Appendix F1 – Assessment of Controls (Watershed Restoration Assessment)

WHEEL CREEK
WATER CHEMISTRY MONITORING
YEAR 12 REPORT

Prepared for:

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1.0 INTRODUCTION

Harford County conducts monitoring in the Wheel Creek watershed to evaluate the benefits of various improvement projects, including stormwater pond retrofits and stream restorations. Wheel Creek has been identified as the County's priority watershed to satisfy National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) permit-required monitoring.

Wheel Creek watershed drains 435 acres consisting of high density residential and commercial land uses in the headwaters, and medium and low density residential and forest land uses in the remainder. The streams in the watershed have been altered by changes in hydrology associated with recent urbanization and historical agricultural land use. Imperviousness has increased to 27% in the past three decades of development (Harford County DPW 2008). In total, eight individual construction projects have been completed in tributaries and stormwater facilities in the watershed during 2012 to 2017 in an effort to improve instream chemical, biological, and physical conditions.

Monitoring to assess the effectiveness of the restoration effort in the Wheel Creek watershed to comply with the requirement of the MS4 permit has been ongoing since 2009. Harford County contracted with Versar, Inc., to conduct water chemistry and continuous flow monitoring. Previously, monitoring was performed in conjunction with requirements associated with the Chesapeake and Atlantic Coastal Bays 2010 Trust Fund stream restoration initiative, which included funding for the restoration projects and continuous flow, biological, and physical monitoring performed by Maryland Department of Natural Resources (DNR). Monitoring requirements for the Trust Fund stream restoration initiative have since been satisfied. Baseflow water chemistry monitoring, previously undertaken by County staff, has been conducted by Versar from 2018 to the present. Continuous flow monitoring near all three of the water chemistry monitoring stations has been conducted by Versar from June 2016 to the present. Biological and physical monitoring have been conducted by KCI Technologies beginning in 2019. Geomorphological assessments have been conducted annually since 2010, first by the County and subsequently by Versar. United States Geological Survey (USGS) operates a stream flow gauging station near the mouth of Wheel Creek (USGS Station 0158175320) and a stage level gauging station and tipping bucket rain gauge in Atkisson Reservoir (USGS Station 01581753).

This report documents the water chemistry monitoring activities undertaken by Harford County, Versar, and USGS, and summarizes the data obtained from July 1, 2021 to June 30, 2022. The activities included capturing eight wet weather events, monthly baseflow monitoring, and continuous flow rate monitoring in the Wheel Creek watershed. Of note, the final wet weather event of FY2021 initiated on June 30, 2021, counting towards the permit requirements for Harford County, but continued until July 2, 2021. As such, discharge and chemical results fell within this permit year and are included in this assessment. An assessment of long-term pollutant concentration trends and reduction by the restoration projects is also presented.

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2.0 STUDY AREA AND STUDY DESIGN

Wheel Creek forms a portion of the Atkisson Reservoir Watershed and resides within the Bush River Basin. It consists of approximately 435 acres of watershed, 2.2 linear stream miles, and five stormwater management facilities. Four stream reaches were targeted for restoration and four stormwater facility retrofits were planned in the drainage area (Harford County DPW 2008). Restoration and retrofit activities began in 2012 and continued through April 2017 (Table 2-1). Pre-restoration and post-restoration data will be used to assess performance of portions of the stream restoration and stormwater BMP retrofit projects as well as for the overall watershed. The current monitoring period represents the fourth full year of post-restoration data collection and analyses.

Table 2-1. Timeline of restoration and retrofit projects in Wheel Creek watershed (M. Dobson pers. comm.)

Construction Projects	Start Date	Completion Date
Gardens of Bel Air (Pond A)	September 8, 2012	December 20, 2012
Calverts Walk (UMS-1)	January 14, 2013	April 4, 2013
Festival of Bel Air (Pond C)	May 12, 2015	August 7, 2015
Country Walk 1A (Pond D)	September 21, 2015	December 11, 2015
MMS-5, MB-4, MB-1	December 7, 2015	February 26, 2016
Water Quality Facilities (4)	December 7, 2015	March 18, 2016
Lower Wheel Creek	September 19, 2016	March 2017
Country Walk 1B (Pond E)	December 2016	April 2017

The water chemistry monitoring study design employs before and after conditions assessments corresponding to comparisons of pre- and post-restoration and retrofit phases. The initiation, termination, and duration of the phases vary by station and the schedule of restoration construction.

Three long-term automated water chemistry sampling and flow logging stations were established at Stations WC002, WC003, and WC004 (Figure 2-1). Station WC004 is located on the middle branch, immediately downstream of the stormwater retrofit at Festival Shopping Center (Point C). Stations WC003 and WC004 bracket completed stormwater retrofits at Pond D and Pond E along the middle branch. Station WC002 is located on the mainstem and water chemistry data collected there will provide an overall assessment of the benefits of retrofit and restoration projects in upstream tributaries (Figure 2-2). Baseflow monitoring took place at three stations along the Wheel Creek main stem and tributaries (WC002, WC003, and WC004).

Figure 2-1. Wheel Creek Watershed long-term water chemistry monitoring stations

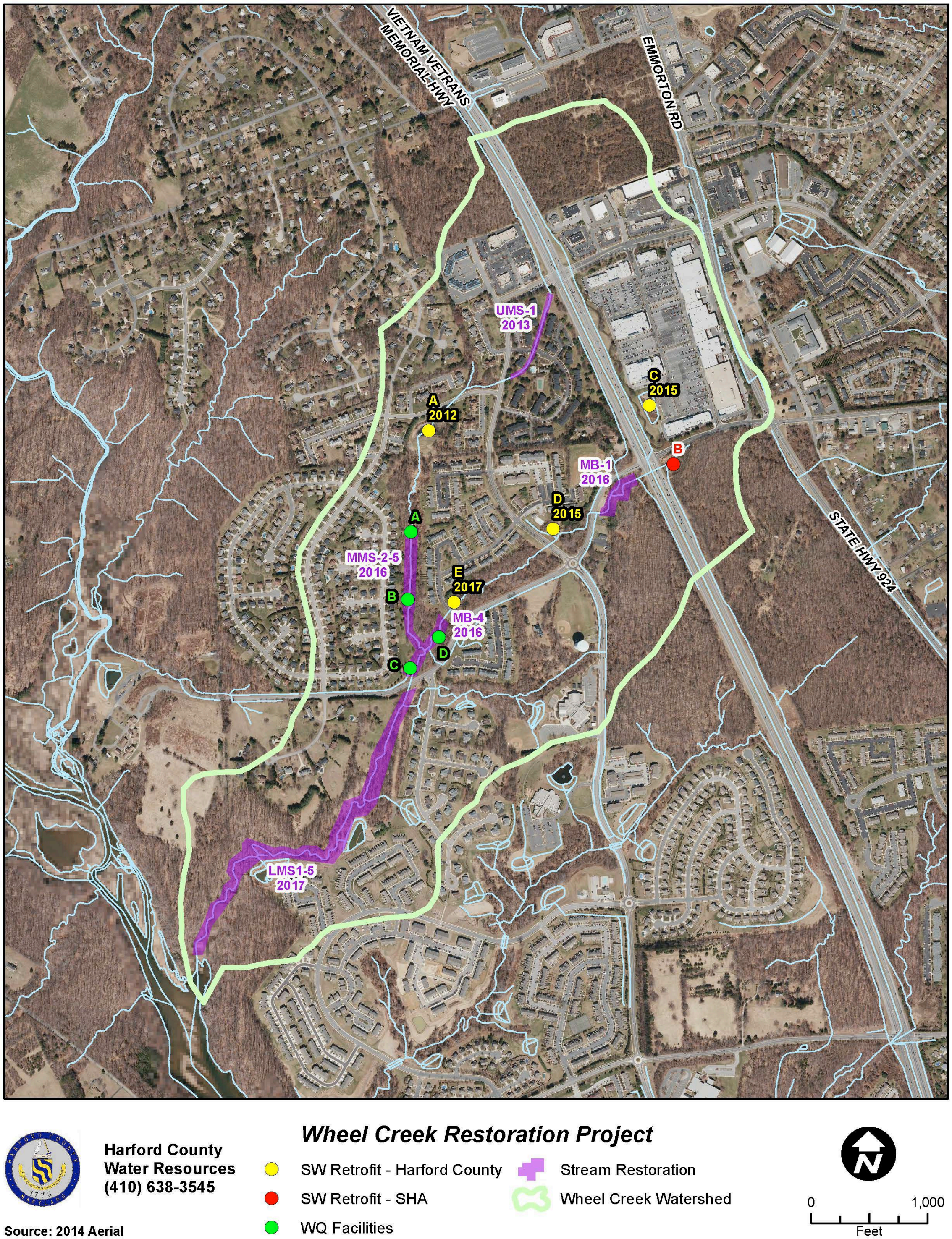

Figure 2-2. Stream restoration and stormwater retrofit sites in Wheel Creek watershed.

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3.0 METHODS AND MATERIALS

3.1 STORMFLOW MONITORING

Fixed, automated stormflow monitoring and long-term flow logging stations were situated at the following locations:

- WC002 – Wheel Creek mainstem at Wheel Road
- WC003 – Middle branch at Cinnabar Lane
- WC004 – Middle branch off Wheel Court

Stormflow samples were collected by Versar staff using American Sigma 900Max samplers at Stations WC002, WC003, and WC004 working in conjunction with ISCO 4230 bubbler flow meters. Automated sampling equipment was installed in September 2010 at Station WC002 and Station WC003 and mid-October 2010 at Station WC004. During storms, bubbler flow meter tubing and carriers were secured at the downstream end of culverts at Station WC002 and Station WC003 while the bubbler tube at Station WC004 was secured instream. Automated samplers contained 24, one-liter polypropylene bottles and were programmed to start at a specific time (based on the storm forecast) by field staff to sample the rising, peak, and falling limbs of the storm on a time-paced basis. Separate composite samples were created on a discharge volume-proportional basis to represent the rising, peak, and falling limbs of the stream hydrograph.

Eight events were monitored between July 1, 2021 and June 30, 2022 (Table 3-1); storm characteristics for the June 30, 2021 overlapped with FY2022 and are therefore included in this reporting year. Event rainfall duration was calculated from the first to the last measurable amounts of rain that triggered the tipping mechanism within the rain gauge. Antecedent dry time was calculated by determining the time interval between the initiation of rainfall for the monitored event and the cessation of rainfall for the prior event. Qualifying storm events required a minimum of 24 hours where there had been less than 0.03 inches total accumulated rainfall.

Flow rate during monitored storm events was determined using Manning's equations specific to each outfall pipe at Stations WC002 and WC003 and by rating curve at Station WC004. The rating curve at Station WC004 was prepared using directly-measured velocities, over a range of stages, along a stream channel cross-section (Appendix B). Versar field staff measured velocity and channel depth using a Marsh-McBirney Flowmate 2000 flowmeter, with sensor attached to a graduated wading rod (Jones and Hage 2011). Automated storm sampling procedures are described in fuller detail in the project's Quality Assurance and Quality Control Document (Corbin et al. 2021). The duration of a storm event was recorded as the time of elevated flow (Appendix A). Stations WC003 and WC004 were found to have flow levels above baseflow longer than Station WC002 for several monitored storm events. These prolonged periods of elevated flow for these stations were possibly due to the stormwater ponds upstream of them detaining and releasing water over an extended period of time, where the continued discharge from these stormwater ponds contributed to flows above baseflow in the smaller upstream station systems where channels are narrower, and flows elevate easier.

Stream water samples were tested for the analytes listed in Table 3-2. Since May 2013, samples were tested for an expanded suite of analytes that included turbidity and chloride. Analytes with multiple detection limits are presented as a range in Table 3-2.

Table 3-1. Statistics for monitored storms, July 2021 – June 2022

Date	Rainfall Total (in.)	Rainfall Duration (hr.)	Antecedent Dry Time (hr.)
30-Jun-21	1.07	24.0	199.02
19-Aug-21	0.18	24.0	72.05
3-Sep-21	4.30	30.0	85.43
13-Dec-21	0.14	14.0	101.00
10-Jan-22	0.25	28.0	69.77
20-Jan-22	0.46	18.0	65.05
10-Mar-22	0.38	17.0	68.97
9-May-22	2.95	52.0	48.18
19-May-22	0.34	18.0	57.67

Rainfall recorded by primary onsite rain gauge at Station WC002

Table 3-2. Parameters, methods, detection limits, and water quality criteria for Wheel Creek monitoring

Parameter	Analytical Method	Reporting Limit (mg/L)	Method Detection Limit (mg/L)	MD Freshwater Criteria[a]		EPA Recommended Ambient Water Quality Criteria[b] (mg/L)
				Acute (µg/l)	Chronic (µg/l)	
BOD-5	SM 5210 B	0.9-27	0.2-27			
Nitrate + Nitrite	SM 4500 NO3F	0.1-0.2	0.02-0.1			0.69 (Total N)[c]
Total Kjeldahl Nitrogen	SM 4500 NorgD	0.5	0.06-0.3			
Orthophosphate	SM 4500 PE	0.02-0.05	0.01-0.02			
Total Suspended Solids	SM 2540D	1-4	2.4			
Copper	EPA 200.8	0.002	0.0002-0.001	13	9	
Lead	EPA 200.8	0.001	0.00006-0.0003	65	2.5	
Zinc	EPA 200.8	0.01	0.0004-0.002	120	120	
Chloride[d]	EPA 300.0	5-50	5-50			860 (acute) 230 (chronic)
Ammonia	SM 4500 NH3H	0.1-0.3	0.04-0.05			
Total Phosphorus	SM 4500 PB&E	0.05-0.1	0.01-0.1			0.03656
Hardness	SM 2340C	10-20	10-20			
Turbidity	HACH 10258	0.01-1	0.5			
Total Petroleum Hydrocarbons	EPA 1664A	5	5			
E. coli (reported as MPN/100 ml)	SM 9223B	1	1			

(a) Values from COMAR 26.08.02.03-2 (undated).
(b) U.S. EPA 2000. Recommended criteria are derived from the 25th percentile of concentrations in all streams in the ecoregion.
(c) Total nitrogen concentration is the sum of total Kjeldahl nitrogen and combined nitrate plus nitrite.
(d) U.S. EPA 1988. Ambient Water Quality Criteria for Chloride.

Storm event mean concentrations (EMCs) were calculated individually for each storm by obtaining the concentration of each pollutant, weighted according to limb discharge volume. Limb discharges were determined by plotting the portion of the storm hydrograph represented by the composite sample and integrating under the curve using Flowlink software. For TPH and *E. coli*, which were collected by grab during irregular occasions during stormflow, a simple average concentration without flow weighting was calculated ("greater than" *E. coli* results were set to the numerical result).

Estimated pollutant loading values for each storm were determined by multiplying the storm EMCs by the total storm discharge in cubic feet. Total storm discharge was determined by plotting the storm hydrograph and integrating under the curve using Flowlink software.

3.2 BASEFLOW MONITORING

Baseflow monitoring was completed monthly by Versar staff. Grab samples were collected at the locations listed below.

- WC002 – Wheel Creek mainstem at Wheel Road
- WC003 – Middle branch at Cinnabar Lane
- WC004 – Middle branch off Wheel Court

3.3 LONG-TERM FLOW RATE LOGGING

Long-term flow rate logging was conducted at Stations WC002, WC003, and WC004 described above. Maryland DNR installed Solinst flow loggers in 2012 and maintained them through June 2016, at which point Versar assumed responsibility for monitoring and maintenance. Versar conducted monthly site inspections, logger downloads, and baseflow discharge measurements between July 2021 and June 2022. Storm discharge measurements were also collected whenever possible to verify the rating curve at each station.

During the winter months, the Solinst flow loggers were removed from service to prevent damage to the sensors due to icing. During these periods, ISCO 4230 bubbler flow meters were installed to capture level data while the Solinst loggers were offline.

Complete flow series for each station were compiled from the Solinst and ISCO logger data. Staff performed quality control on the level time series to remove any anomalous data (e.g., resulting from manipulation during Solinst data offloads). Levels were corrected to reflect observed staff gauge readings, and linear drift corrections were applied to the time series at each station to compensate for logger drift. A rating curve was established at each of the three logging stations to convert each logger's level data to flow rate (Appendix B).

3.4 RAINFALL LOGGING

Rainfall was recorded by an Onset HOBO electronic, tipping-bucket rain gauge situated in an open area near Station WC002. The gauge was downloaded and maintained by Versar field staff and is the primary gauge used for storm event rainfall totals. Daily rainfall recorded by the gauge is presented in Appendix C. Rainfall records from USGS' Atkisson Reservoir gauge (0.8 miles away to the SW), the secondary rainfall recorder, were used to supplement the onsite data in cases where onsite gauge data were unavailable due to power interruptions or mechanical failures. When the onsite rain gauge experienced a malfunction, a local Weather Underground station (www.wunderground.com; Bel Air South Station) was used for storm event rainfall totals since it is closer to the monitoring stations than the USGS gauge; the USGS rain gauge represents the official totals used for comparison over the entire duration of the year.

3.5 DETERMINATION OF STORM EVENT POLLUTANT LOADS

Pollutant loads were determined by multiplying the pollutant event mean concentration (a stream flow volume-weighted mean of analytical results from laboratory analysis) by the total storm discharge at the point of sample collection. Stream discharge volume for a specific time interval (for a specific limb or the total event) is determined by integrating under the flow rate hydrograph over the time period of interest. The pollutant event mean concentration (EMC) for a given storm is determined by:

$$\mathrm{EMC} = \frac{\sum_{i=1}^{3} C_i V_i}{\sum_{i=1}^{3} V_i}$$

Where:

EMC = Event Mean Concentration of specific pollutant

i = Numerical representation of storm limb (1=rising, 2=peak, 3=falling)

C_i = Pollutant concentration at limb i

V_i = Corresponding discharge represented by composite sample collected for limb i.

The average pollutant EMC for the monitoring year is an arithmetic mean of individual storm EMCs.

Pollutant load for a given storm is calculated by:

$$L = (k_1 / k_2) \times (\mathrm{EMC} \times V_T)$$

Where:

L = estimated load in pounds
k_1 = conversion factor 28.317 liters per cubic foot
k_2 = conversion factor of 453,592.4 milligrams per pound
V_T = estimated total storm runoff in stream in ft^3

The average pollutant load for the monitoring year is an arithmetic mean of individual storm loads.

3.6 DETERMINATION OF AVERAGE ANNUAL AND SEASONAL EMC AND TOTAL ANNUAL AND SEASONAL LOAD

Average annual storm EMCs for each pollutant at each station were determined by obtaining the arithmetic mean of individual storm EMC data for a given year. Average annual baseflow Mean Concentrations (MCs) were developed by calculating the arithmetic mean of concentration data. Average seasonal EMCs and MCs were obtained by using the same method, except on a seasonal basis. Below-reportable detection limit results were set to zero when determining average EMCs and determining baseflow MCs.

Total annual load was determined by (a) multiplying all stormflow volume in a given year at a given station by the corresponding average annual EMC for each pollutant, (b) multiplying all baseflow volume in the same year by the corresponding average annual MC, and (c) summing the result.

3.7 SUSPENDED SEDIMENT TRANSPORT MONITORING

Suspended sediment transport was monitored at all three Wheel Creek storm monitoring stations, WC002, WC003, and WC004 (Figure 2-1). Sediment samples were collected in conjunction with wet weather samples from July 2021 through June 2022. Suspended sediment was monitored during eight wet weather sampling events using a modified siphon sampler (Diehl 2008) outfitted with a HOBO® U20 depth logger for continuous stage recording. The modified siphon sampler was developed by USGS to sample shallow water at closely spaced vertical intervals, enabling samples to be collected passively at multiple stages of the rising limb of the hydrograph. Each sampler included six 1000-mL sample containers oriented horizontally with an intake tube and an air vent, which allowed sample collection at up to six two-inch incremental stages. Samples collected were analyzed individually for suspended sediments following a standard method for total suspended solids (SM2540D; APHA 1999), with filtration of the full 1000-mL sample.

Since the sampler devices could not be deployed in the same location as the gauge recorders without causing interference, discharge corresponding to each sample was determined using depth data obtained from the HOBO® loggers. The loggers were set to record pressure and temperature data at 5-minute intervals for the full duration of their deployment. The logger data were then post-processed using HOBOware Pro 2.7.3 software, to correct for changes in barometric pressure. The resulting data were used to determine the approximate time that each sample bottle was filled, and the corresponding discharge from the time of sample collection was obtained from the storm event flow rate graphs for each station. The relationship between discharge and suspended sediment concentration was then plotted to create a sediment-transport curve (Glysson 1987) for each station.

3.8 STATISTICAL TEST FOR TREND

A Kendall's Tau-b statistical test (Kendall 1948) was performed on the compiled baseflow concentration and individual storm EMC data at the monitoring stations. This test is a non-parametric test that compares the ranks of parameter concentrations to the ranked collection dates. The test was used to determine whether a significant upward or downward trend in concentration occurred over time.

3.9 COMPARISON OF PRE- TO POST-RESTORATION DATA

The assessment of the effectiveness of restoration projects in Wheel Creek relies upon comparisons of pre-restoration conditions to post-restoration conditions. Because the implementation of restoration projects in the watershed was staggered, the effectiveness of groups of the projects was determined strategically using the location of the applicable monitoring station and construction timelines. The time periods for the pre-restoration and post-restoration conditions were appropriately defined at each station, so that the during-construction phases were eliminated from the comparisons. Note the following:

- Pre-restoration and post-restoration conditions evaluated using data from Station WC004 were governed only by the construction of Pond C at Festival of Bel Air,
- Pre-restoration phase for data collected at Station WC002 was governed by the earliest construction of projects on the mainstem (i.e., Pond A in September 2012),
- Pre-restoration phase for data collected at Station WC003 was governed by the start of construction at Pond C in May 2015 (same as at Station WC004) but was set to the same timeframe as Station WC002 for consistency, and
- Post-restoration phase at both Station WC002 and Station WC003 was set to the conclusion of construction of Pond E at Country Walk 1B in April 2017 since the effort was upstream of both stations.

The relationship between restoration construction schedule, which monitoring station data are used in efficiency evaluations, and the type of evaluations are provided in Table 3-3.

Comparisons were conducted in two ways: a) total annual load for fiscal years 2017-2022 (post-restoration) to 2010-2011 (pre-restoration); and b) post-restoration storm EMCs and baseflow MCs to pre-restoration storm EMCs and baseflow MCs.

3.9.1 Comparison of Ratios Between Stations WC002 and WC003

Because only one monitoring station is located on the mainstem, the assessment of the effectiveness of restoration projects in improving water quality in the mainstem, as well as projects on the middle branch located between Station WC002 and Station WC003 (e.g., MB-4 and one water quality facility), was isolated and performed indirectly by comparing ratios of pollutant loads and concentrations between the stations during the pre-restoration and post-restoration phases. The ratio (or relationship) of pollutant levels between the two stations during the pre-restoration period was taken as a baseline; a lowering of the ratio during the post-restoration period would indicate pollutant reduction between the stations.

The ratio of total load between the downstream station and the upstream station was calculated for the following pollutants: total nitrogen, total phosphorus, total suspended solids (TSS), ammonia, BOD, copper, lead, and zinc.

For this method, total loads were calculated using data from the pre-restoration period (2010-2011) and post-restoration period (FY 2017-2022) and then compared to one another. The ratio between stations is calculated from the following equation:

$$\text{Ratio} = (1 - (L_3/L_2)) * 100$$

Where:

L_3 = Load at Station WC003 (upstream)
L_2 = Load at Station WC002 (downstream)

To determine restoration effectiveness in terms of storm EMC and baseflow MC, the ratio between the average EMC or MC at the downstream Station WC002 and the upstream Station WC003 was calculated for the pre-restoration time period and the post-restoration time period. The ratios of average concentrations between the downstream station and the upstream station, during both periods, were compared for each analyte. The ratio between stations is calculated from the following equation:

$$\text{Ratio} = (1 - (C_3/C_2)) * 100$$

Where:

C_3 = Concentration at Station WC003 (upstream)
C_2 = Concentration at Station WC002 (downstream)

A paired Student's t test was used to determine significance of the difference in EMC or MC between the stations.

3.9.2 Comparison of Pre- and Post-Restoration Conditions at all Stations

Calculations of absolute pollutant removal efficiencies were used to characterize the aggregated effectiveness of restoration projects located within each station's subwatershed. Both storm EMC and baseflow MC data accumulated during the pre-restoration and post-restoration phases at each station, defined above, were compared. The efficiencies were calculated using the same percentage equation defined in Section 1.2.1. A Student's t test was used to determine significance.

Table 3-3. Restoration construction schedule, applicable monitoring stations, and recommended efficiency evaluation methods

Construction Projects	Reach	Start Date	Completion Date	No. Storms		No. Baseflows		Efficiency Evaluation
				Pre-restoration	Post-restoration	Pre-restoration	Post-restoration	
Gardens of Bel Air (Pond A)	Mainstem	September 8, 2012	December 20, 2012	17 (WC002) 18 (WC003)	49 (WC002) 48 (WC003)	33 (WC002) 32 (WC003)	74 (WC002) 74 (WC003)	Compare differences between WC002 & WC003 during pre- and post-conditions
Calverts Walk (UMS-1)	Mainstem	January 14, 2013	April 4, 2013					
MMS-5, MB-4	Mainstem, Middle Branch	December 7, 2015	February 26, 2016					
Water Quality Facilities (4)	Mainstem (3), Middle Branch (1)	December 7, 2015	March 18, 2016					
Festival of Bel Air (Pond C)	Middle Branch	May 12, 2015	August 7, 2015	42	58	52	81	WC004 before & after
Country Walk 1A (Pond D)	Middle Branch	September 21, 2015	December 11, 2015	17 (WC002) 18 (WC003)	42 (WC002) 43 (WC003)	33 (WC002) 32 (WC003)	60 (WC002) 60 (WC003)	WC002 before & after; WC003 before & after
MB-1	Middle Branch	December 7, 2015	February 26, 2016					
Country Walk 1B (Pond E)	Middle Branch	December 2016	April 2017					

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4.0 RESULTS AND DISCUSSION

Results of stormflow and baseflow sampling performed from July 1, 2021 through June 30, 2022 are presented and discussed in this section. The individual sample analytical data are compiled into tables while annual average concentrations and loadings are presented in tabular and graphical form.

4.1 STORMFLOW CONCENTRATION RESULTS

Analytical results for storm samples collected at each of the three stations are presented in Table 4-1. Total nitrogen results were greater than the EPA recommended reference value of 0.69 mg/L (U.S. EPA 2000) in 97.5% of the samples in this monitoring period. Of the samples in which total phosphorus was detected, 74.3% of the results were greater than the EPA recommended reference value of 0.03656 mg/L. Orthophosphate was detected in 56.8% of stormflow samples collected. Ammonia results were above the detection limit in 66.7% of stormflow samples collected at all stations during the year. Ammonia concentrations were highest at all three stations during the May storm event. BOD was detected in 79.0% of samples, with the highest concentrations at all three stations during the August storm event.

Zinc was detected in 98.8% of storm samples collected between July 1, 2021 and June 30, 2022. No zinc concentration was greater than MDE's acute criterion for surface water in samples collected during this reporting period (Table 3-2).[1] Zinc concentrations were highest during the January 10, 2022 storm event. Lead concentrations were above the detection limit in 76.5% of the samples, none of which were above the MDE acute criterion. Copper concentrations were above the detection limit in 96.3% of samples; however, only 2.5% were greater than the MDE acute criterion for surface water.

E. coli concentrations were equal to or greater than the maximum reportable result (2,420 MPN/100ml) in 18.5% of stormflow grab samples. *E. coli* concentrations were generally highest at Station WC002 in FY2022, with concentrations of *E. coli* decreasing at Station WC003 and WC004, respectively. TPH was not detected in any of the 27 stormflow grab samples collected at the monitoring stations. Hardness was generally the lowest at Station WC004. Turbidity was generally highest at Stations WC003 and WC004, probably due to the additive effects of suspended matter transported from the stormwater collection ponds just upstream of these stations. TSS was above the detection limit in 82.7% of samples, with highest concentrations also at Stations WC003 and WC004. Chloride was reported in 95.1% of the storm runoff samples, but only one of the reported results exceeded the acute criterion established by USEPA, occurring during the peak limb of the January 10, 2022 storm event. Chloride concentrations were much higher in FY2022 and FY2021 than in FY2020, but less than those seen in FY2018 and FY2019; probably due to the moderate winter and smaller quantities of deicing compound applied on road surfaces in FY2022 and FY2021 compared to other years.

[1] The zinc, lead, and copper criteria are based on the dissolved form, while the laboratory analytical results are for total metal concentration. Comparisons to surface water criteria are for discussion purposes only and do not imply violations of surface water standards.

4.2 BASEFLOW CONCENTRATION RESULTS

Baseflow sample analytical results are presented in Table 4-2. Under baseflow conditions, concentration values for total phosphorus were above the detection limit in 69.4% of samples. Orthophosphate was detected in 8.3% of the baseflow samples. Ammonia was detected in 83.3% of samples, including all Station WC002 and all but one Station WC003 samples, and TSS was detected in 58.3% of baseflow samples. Total nitrogen was above the detection limit in all the baseflow samples, and all concentration levels were greater than the EPA reference value (0.69 mg/L). Total nitrogen concentrations tended to be lowest at Station WC003 and highest at Station WC004.

Zinc was detected in all baseflow samples and had the highest concentrations at Station WC004. Lead and copper were detected in 33.3% and 52.8%, respectively, of baseflow samples. All concentrations of all metals were lower than MDE's applicable chronic surface water criteria.

BOD was detected in 19.4% of samples. Baseflow concentrations of nitrate plus nitrite were higher at Station WC004 than at the other stations. Turbidity was generally lowest in baseflow samples taken from Station WC004 and highest in baseflow samples taken from Station WC003.

Chloride concentrations were generally elevated from January through April for all stations. Chloride was highest at Station WC004 for a given baseflow sampling event and became gradually lower when progressing downstream to Station WC002. The maximum observed chloride concentrations for Stations WC003 and WC004 occurred during the February sampling event and for Station WC002 occurred during the January sampling event. The lowest chloride concentrations occurred during the July sampling event at Station WC002 and WC003, and during the March sampling event at Station WC004.

Hardness, a characteristic of surface waters, was quantified in all baseflow samples. Concentrations greater than 120 mg/L are considered "Hard", while concentrations exceeding 180 mg/L are considered "Very Hard". All baseflow samples collected contained "Hard" water and 44.4% of all baseflow samples collected contained "Very Hard" water, and the highest hardness values were found at Station WC004, where 83.3% of collected samples were considered "Very Hard".

E. coli bacteria concentrations were detected in all baseflow samples at all stations, ranging in concentration from 9.6 to >2,420 MPN/100ml. The maximum concentration during the monitoring period for Station WC002 occurred during the October sampling event, and the maximum concentration for Stations WC003 and WC004 occurred during the June sampling event. In general, *E. coli* concentrations were highest during the warmer months and lowest during the colder months.

TPH was not detected in any of the baseflow samples collected from the study area during the monitoring period.

Table 4-1. Stormflow water chemistry results, July 2021 – June 2022. All concentrations are in units of mg/L unless indicated.

Storm Date	Limb	Discharge (cf)	5-Day BOD	Ammonia	Nitrate + Nitrite	Orthophosphate	TKN	Total P	TSS	Copper (µg/l)	Lead (µg/l)	Zinc (µg/l)	TPH	*E. coli* (MPN/ 100 ml)	Total Nitrogen	Hardness	Chloride	Turbidity (NTU)
Station WC002																		
6/30/2021	Rising	52,140	3.6	<0.10	0.75	<0.02	0.86	0.13	<4.0	7	0.6	13	N.C	N.C.	1.61	74	60.60	6.16
6/30/2021	Peak	279,654	<2.0	<0.10	1.52	0.04	0.64	<0.10	<4.0	3	0.1	6	N.C	N.C.	2.16	144	84.40	1.06
6/30/2021	Falling	17,775	<2.0	<0.10	0.79	0.03	0.87	<0.10	<4.0	2	0.3	9	<5	1,410.0	1.66	84	69.70	3.17
8/19/2021	Rising	9,628	3.0	0.29	0.90	0.06	1.30	0.23	76.0	15	4.0	20	N.C	N.C.	2.20	150	105.00	31.80
8/19/2021	Peak	17,760	2.0	0.06	0.60	0.01	0.70	0.05	4.0	3	<1.0	<10	N.C	N.C.	1.30	116	88.70	3.82
8/19/2021	Falling	11,285	1.0	0.07	0.70	<0.05	0.70	0.04	6.0	3	<1.0	3	<5	816.0	1.40	143	106.00	5.61
9/3/2021	Rising	329,668	2.0	0.11	0.40	0.02	0.70	0.09	6.0	6	0.8	19	N.C	N.C.	1.10	42	35.90	5.24
9/3/2021	Peak	1,895,091	3.0	0.05	0.40	0.05	1.20	0.23	63.0	15	3.0	42	<5	>2,420.0	1.60	16	26.90	16.40
9/3/2021	Falling	36,207	<1.0	<0.30	0.50	0.02	0.50	0.07	<2.0	3	0.2	10	N.C	N.C.	1.00	54	<25.00	4.96
12/13/2021	Rising	6,520	<1.0	<0.30	1.40	<0.05	0.50	0.02	<2.0	3	<1.0	12	N.C	N.C.	1.90	176	125.00	1.09
12/13/2021	Peak	6,536	2.0	<0.30	1.00	<0.05	0.90	0.06	25.0	5	0.3	20	N.C	N.C.	1.90	168	108.00	12.90
12/13/2021	Falling	6,543	5.0	<0.30	0.80	0.01	0.70	0.04	5.0	6	<1.0	15	<5	160.0	1.50	210	113.00	7.32
1/10/2022	Rising	7,143	1.0	0.13	1.60	<0.05	0.50	0.02	2.0	1	<1.0	22	N.C	N.C.	2.10	202	548.00	2.20
1/10/2022	Peak	26,508	3.0	0.28	0.60	0.03	1.10	0.07	16.0	6	0.6	44	N.C	N.C.	1.70	168	1,020.00	18.30
1/10/2022	Falling	19,210	2.0	0.17	0.50	0.02	0.90	0.05	8.0	5	0.5	38	<5	387.0	1.40	133	692.00	11.30
1/20/2022	Rising	2,702	<1.0	0.48	1.60	<0.05	0.40	0.01	2.0	1	<1.0	17	N.C	N.C.	2.00	150	206.00	1.56
1/20/2022	Peak	35,169	3.0	0.14	0.50	0.03	0.80	0.08	18.0	9	1.0	27	N.C	N.C.	1.30	56	197.00	13.10
1/20/2022	Falling	12,693	2.0	0.10	0.50	0.03	0.70	0.06	7.0	4	0.4	20	<5	613.0	1.20	60	181.00	10.80
3/10/2022	Rising	12,400	1.0	0.07	1.30	<0.05	0.60	0.02	<2.0	2	<1.0	14	N.C	N.C.	1.90	168	183.00	3.37
3/10/2022	Peak	24,494	3.0	0.09	0.80	0.02	0.90	0.05	14.0	5	0.5	20	<5	1,200.0	1.70	120	212.00	15.20
3/10/2022	Falling	10,573	2.0	0.06	0.70	0.02	0.70	0.03	<2.0	4	<1.0	15	N.C	N.C.	1.40	100	201.00	5.87
5/9/2022	Rising	39,000	3.0	0.17	0.60	0.01	1.40	0.18	21.0	4	0.6	18	<5	>2,420.0	2.00	92	81.40	5.78
5/9/2022	Peak	353,175	2.0	<0.30	0.30	0.03	1.00	0.07	10.0	9	0.7	20	N.C	N.C.	1.30	34	17.70	14.60
5/9/2022	Falling	49,102	1.0	0.07	0.50	0.02	0.90	0.05	5.0	8	<2.0	21	N.C	N.C.	1.40	64	37.60	10.70
5/19/2022	Rising	3,133	2.0	0.12	1.40	<0.05	0.70	0.03	8.0	<2	<1	12	N.C	N.C.	2.10	176	128.00	4.84
5/19/2022	Peak	15,361	6.0	0.44	0.70	0.02	1.60	0.11	39.0	5	1.0	29	N.C	N.C.	2.30	88	62.00	12.10
5/19/2022	Falling	9,147	4.0	0.33	0.60	<0.05	1.20	0.05	8.0	2	<1	13	<5	1,730.0	1.80	68	52.00	7.03

N.C. = Sample Not Collected

Table 4-1. (Continued)

Storm Date	Limb	Dis-charge (cf)	5-Day BOD	Ammo-nia	Nitrate + Nitrite	Ortho-phos-phate	TKN	Total P	TSS	Copper (µg/l)	Lead (µg/l)	Zinc (µg/l)	TPH	*E. coli* (MPN/ 100 ml)	Total Nitro-gen	Hard-ness	Chlor-ide	Turbid-ity (NTU)
Station WC003																		
6/30/2021	Rising	51,728	6.1	0.27	0.45	<0.02	1.72	0.17	6.0	6	0.7	16	N.C	N.C.	2.17	95	66.10	8.94
6/30/2021	Peak	140,662	2.6	<0.10	0.41	0.02	0.96	<0.10	6.8	7	0.9	16	N.C	N.C.	1.37	54	58.50	12.40
6/30/2021	Falling	15,000	<2.0	<0.10	0.66	0.02	1.22	<0.10	<4.0	2	0.3	7	<5	1,550.0	1.88	88	88.70	3.92
8/19/2021	Rising	1,750	3.0	0.23	0.70	<0.05	3.30	0.27	14.0	4	0.1	9	N.C	N.C.	4.00	166	123.00	6.30
8/19/2021	Peak	5,324	1.0	0.07	0.40	<0.05	0.70	0.04	5.0	3	0.2	6	N.C	N.C.	1.10	130	108.00	4.57
8/19/2021	Falling	2,418	<1.0	0.09	0.50	<0.05	0.40	0.03	3.0	3	<1.0	6	<5	488.0	0.90	140	110.00	2.66
9/3/2021	Rising	130,179	2.0	<0.30	0.30	0.07	0.70	0.07	11.0	5	0.7	14	N.C	N.C.	1.00	56	<25.00	6.09
9/3/2021	Peak	951,284	2.0	0.07	0.30	0.05	1.00	0.11	32.0	2	0.2	8	<5	1,410.0	1.30	48	43.80	15.80
9/3/2021	Falling	20,211	<1.0	<0.30	0.30	<0.05	0.40	0.03	2.0	10	1.0	25	N.C	N.C.	0.70	32	35.60	4.17
12/13/2021	Rising	363	2.0	<0.30	0.80	<0.05	0.80	0.08	24.0	3	0.3	16	N.C	N.C.	1.60	212	157.00	6.86
12/13/2021	Peak	392	2.0	<0.30	0.90	<0.05	0.80	0.06	18.0	8	1.0	42	N.C	N.C.	1.70	210	182.00	12.10
12/13/2021	Falling	354	2.0	<0.30	1.00	<0.05	0.60	0.02	5.0	4	<1.0	14	<5	20.3	1.60	194	156.00	4.81
1/10/2022	Rising	4,341	<1.0	0.07	0.90	<0.05	0.50	<0.05	4.0	<2	<1.0	16	N.C	N.C.	1.40	172	240.00	4.29
1/10/2022	Peak	12,846	2.0	0.22	0.50	0.02	0.90	0.07	16.0	5	0.5	38	N.C	N.C.	1.40	186	731.00	16.30
1/10/2022	Falling	6,615	2.0	0.14	0.40	0.02	0.80	0.03	7.0	4	0.3	36	<5	206.0	1.20	174	703.00	7.06
1/20/2022	Rising	2,013	2.0	0.22	1.10	<0.05	0.50	0.02	3.0	3	<1.0	21	N.C	N.C.	1.60	168	288.00	2.25
1/20/2022	Peak	24,291	3.0	0.18	0.40	0.02	0.80	0.06	14.0	5	0.6	23	N.C	N.C.	1.20	69	253.00	9.90
1/20/2022	Falling	8,613	2.0	0.18	0.40	0.02	0.70	0.05	6.0	3	0.5	22	<5	291.0	1.10	66	246.00	7.40
3/10/2022	Rising	2,982	2.0	<0.30	0.90	<0.05	0.80	0.04	11.0	3	0.5	17	N.C	N.C.	1.70	208	243.00	10.50
3/10/2022	Peak	15,062	3.0	0.09	0.60	0.02	0.90	0.05	17.0	5	0.6	20	<5	649.0	1.50	144	330.00	12.10
3/10/2022	Falling	2,738	2.0	<0.30	0.50	0.02	0.80	0.02	<2.0	3	<1.0	14	N.C	N.C.	1.30	130	363.00	5.58
5/9/2022	Rising	36,000	3.0	0.11	0.60	<0.05	1.70	0.17	19.0	10	2.0	51	<5	>2,420.0	2.30	128	144.00	5.89
5/9/2022	Peak	91,028	2.0	0.06	0.20	0.02	1.00	0.06	8.0	8	0.7	17	N.C	N.C.	1.20	36	33.80	12.30
5/9/2022	Falling	31,890	1.0	<0.30	0.30	<0.05	0.90	0.04	8.0	9	0.6	19	N.C	N.C.	1.20	50	39.50	10.60
5/19/2022	Rising	823	3.0	0.19	0.80	<0.05	1.30	0.06	26.0	3	1.0	27	N.C	N.C.	2.10	156	150.00	16.70
5/19/2022	Peak	13,602	3.0	0.26	0.50	<0.05	1.30	0.05	10.0	4	0.5	18	N.C	N.C.	1.80	84	83.90	9.46
5/19/2022	Falling	7,528	2.0	0.13	0.50	<0.05	0.90	0.03	6.0	<2	<1.0	11	<5	1,990.0	1.40	124	111.00	4.51

N.C. = Sample Not Collected

Table 4-1. (Continued)

Storm Date	Limb	Dis-charge (cf)	5-Day BOD	Ammo-nia	Nitrate + Nitrite	Ortho-phos-phate	TKN	Total P	TSS	Copper (µg/l)	Lead (µg/l)	Zinc (µg/l)	TPH	*E. coli* (MPN/ 100 ml)	Total Nitro-gen	Hard-ness	Chlor-ide	Turbid-ity (NTU)
Station WC004																		
6/30/2021	Rising	18,631	3.1	<0.10	0.62	<0.02	2.04	0.11	<4.0	7	1.0	36	N.C	N.C.	2.66	86	97.20	7.12
6/30/2021	Peak	61,566	2.1	<0.10	0.19	<0.02	0.83	<0.10	<4.0	5	0.5	15	N.C	N.C.	1.02	26	<50.00	5.28
6/30/2021	Falling	3,300	<2.0	<0.10	0.36	0.02	0.76	<0.10	<4.0	2	0.4	11	<5	>2,420.0	1.12	50	39.80	2.47
8/19/2021	Rising	1,308	34.0	<0.30	<0.20	<0.05	0.90	0.09	28.0	9	0.9	24	N.C	N.C.	0.90	122	102.00	11.90
8/19/2021	Peak	3,693	2.0	0.07	0.10	<0.05	0.80	0.05	11.0	11	2.0	24	N.C	N.C.	0.90	92	69.80	6.19
8/19/2021	Falling	1,153	1.0	0.12	0.70	<0.05	0.90	0.02	<2.0	3	0.1	10	<5	261.0	1.60	138	125.00	2.31
9/3/2021	Rising	72,001	1.0	<0.30	0.20	0.02	0.60	0.05	8.0	5	0.6	17	N.C	N.C.	0.80	40	32.40	4.40
9/3/2021	Peak	429,755	1.0	<0.30	0.10	0.09	0.50	0.05	9.0	5	0.7	14	<5	727.0	0.60	18	<25.00	4.94
9/3/2021	Falling	6,000	<1.0	<0.30	0.30	0.01	0.30	0.03	4.0	2	0.4	12	N.C	N.C.	0.60	28	30.60	3.66
12/13/2021	Rising	678	<1.0	0.10	2.20	<0.05	0.70	0.02	4.0	3	<1.0	21	N.C	N.C.	2.90	260	153.00	1.48
12/13/2021	Peak	1,217	2.0	0.35	0.50	0.01	1.00	0.05	9.0	6	0.6	26	N.C	N.C.	1.50	82	62.60	6.84
12/13/2021	Falling	621	2.0	0.48	0.50	<0.05	0.90	0.04	3.0	5	0.4	22	<5	126.0	1.40	80	67.80	4.82
1/10/2022	Rising	1,322	2.0	0.27	0.50	0.02	1.00	0.05	10.0	3	0.3	40	N.C	N.C.	1.50	127	377.00	5.63
1/10/2022	Peak	4,597	3.0	0.22	0.30	0.03	1.00	0.06	11.0	5	0.8	58	N.C	N.C.	1.30	121	669.00	10.90
1/10/2022	Falling	2,328	2.0	0.19	0.30	0.02	0.90	0.05	7.0	5	0.5	41	<5	816.0	1.20	88	456.00	9.05
1/20/2022	Rising	678	2.0	0.08	1.30	<0.05	0.70	0.03	7.0	4	0.6	26	N.C	N.C.	2.00	30	148.00	2.58
1/20/2022	Peak	10,718	3.0	0.11	0.30	0.03	0.70	0.05	8.0	2	0.4	28	N.C	N.C.	1.00	167	318.00	6.76
1/20/2022	Falling	3,531	3.0	0.12	0.30	0.02	0.80	0.04	6.0	3	0.4	31	<5	579.0	1.10	43	230.00	7.17
3/10/2022	Rising	1,180	2.0	0.08	2.30	0.01	0.80	0.03	8.0	3	0.3	32	N.C	N.C.	3.10	296	456.00	4.12
3/10/2022	Peak	6,658	4.0	0.13	0.40	0.02	1.30	0.06	10.0	6	0.7	33	<5	93.3	1.70	80	382.00	11.70
3/10/2022	Falling	969	2.0	0.05	0.60	<0.05	0.90	0.04	<2.0	4	<1.0	26	N.C	N.C.	1.50	120	480.00	8.29
5/9/2022	Rising	18,900	3.0	0.16	0.40	0.02	1.60	0.10	5.0	8	1.0	44	<5	>2,420.0	2.00	42	45.40	5.74
5/9/2022	Peak	39,514	1.0	<0.30	0.20	0.03	0.90	0.04	8.0	6	0.5	17	N.C	N.C.	1.10	26	17.20	7.15
5/9/2022	Falling	8,639	<1.0	<0.30	0.40	0.01	0.90	0.03	5.0	6	0.4	19	N.C	N.C.	1.30	42	48.40	6.26
5/19/2022	Rising	507	3.0	0.11	1.60	0.01	1.20	0.06	28.0	3	0.7	32	N.C	N.C.	2.80	212	187.00	11.10
5/19/2022	Peak	5,966	5.0	0.39	0.60	0.02	1.80	0.08	21.0	6	1.0	32	N.C	N.C.	2.40	80	51.40	10.20
5/19/2022	Falling	2,359	4.0	0.33	0.50	<0.05	1.40	0.04	12.0	5	0.4	25	<5	921.0	1.90	64	59.30	6.29

N.C. = Sample Not Collected

Table 4-2. Baseflow water chemistry results, July 2021 – June 2022. All concentrations are in units of mg/L unless indicated.

Baseflow Date	5-Day BOD	Ammonia	Nitrate + Nitrite	Ortho-phosphate	TKN	Total P	TSS	Copper (µg/l)	Lead (µg/l)	Zinc (µg/l)	TPH	*E. coli* (MPN/ 100 ml)	Total Nitrogen	Hardness	Chloride	Turbidity (NTU)
Station WC002																
7/15/2021	<1	0.26	1.3	<0.05	0.8	0.03	<2	0.3	0.08	4	<5	250.0	2.1	134	66.5	1.14
8/5/2021	<1	0.49	1.3	<0.05	0.3	0.02	8	0.6	<1.00	6	<5	211.0	1.6	156	115.0	1.46
9/13/2021	2	0.08	1.1	<0.05	0.4	0.02	<2	0.6	<1.00	7	<5	178.0	1.5	152	101.0	0.95
10/8/2021	<1	0.24	1.2	<0.05	0.5	0.01	2	0.6	<1.00	10	<5	>2,420.0	1.7	170	123.0	0.96
11/18/2021	<1	0.44	1.3	<0.05	0.7	<0.05	8	<2.0	0.06	11	<5	77.6	2.0	158	131.0	1.00
12/9/2021	1	0.38	1.5	<0.05	0.6	<0.05	<2	<2.0	<1.00	9	<5	29.5	2.1	168	126.0	0.47
1/13/2022	<1	0.14	1.7	<0.05	0.6	0.02	12	<2.0	<1.00	14	<5	41.0	2.3	204	279.0	1.84
2/22/2022	1	0.47	1.5	<0.05	0.6	<0.05	2	1.0	0.30	16	<5	41.7	2.1	158	221.0	1.22
3/23/2022	<1	0.08	1.2	<0.05	0.6	<0.05	3	<2.0	<1.00	11	<5	12.2	1.8	161	170.0	1.88
4/25/2022	<1	0.34	1.1	0.01	0.6	<0.05	4	<2.0	<1.00	13	<5	71.2	1.7	164	147.0	1.65
5/10/2022	<1	0.27	1.3	<0.05	0.6	0.02	4	<2.0	<1.00	13	<5	344.0	1.9	160	121.0	1.62
6/15/2022	<1	0.09	0.9	0.02	0.9	0.07	<3	<2.0	<1.00	6	<5	870.0	1.8	138	105.0	2.13
Station WC003																
7/15/2021	<1	0.15	1.2	<0.05	0.7	0.02	2	0.4	0.10	5	<5	299.0	1.9	128	97.3	1.40
8/5/2021	1	0.19	1.0	<0.05	0.4	0.02	31	0.8	0.10	8	<5	172.0	1.4	168	126.0	3.84
9/13/2021	<1	<0.30	0.8	<0.05	0.4	0.02	<2	0.7	<1.00	6	<5	240.0	1.2	151	109.0	1.56
10/8/2021	<1	0.07	1.0	<0.05	0.5	0.02	3	0.9	0.09	11	<5	166.0	1.5	170	144.0	3.21
11/18/2021	1	0.09	0.8	<0.05	0.6	<0.05	2	<2.0	<1.00	11	<5	53.8	1.4	169	156.0	1.94
12/9/2021	<1	0.16	1.1	<0.05	0.7	<0.05	3	<2.0	<1.00	11	<5	73.3	1.8	196	160.0	1.12
1/13/2022	<1	0.14	1.3	<0.05	0.6	0.02	5	<2.0	<1.00	18	<5	107.0	1.9	274	275.0	1.83
2/22/2022	<1	0.08	1.0	<0.05	0.6	<0.05	<2	<2.0	<1.00	14	<5	15.8	1.6	188	299.0	1.09
3/23/2022	<1	0.06	0.8	<0.05	0.7	0.01	8	3.0	0.30	13	<5	27.2	1.5	186	222.0	3.59
4/25/2022	<1	0.11	0.7	<0.05	0.6	0.02	2	<2.0	<1.00	10	<5	65.7	1.3	186	171.0	2.05
5/10/2022	<1	0.08	0.8	<0.05	0.7	0.02	<3	3.0	<1.00	11	<5	120.0	1.5	148	134.0	2.22
6/15/2022	<1	0.09	0.5	<0.05	0.8	0.02	<3	<2.0	<1.00	5	<5	1,550.0	1.3	148	121.0	0.94

Table 4-2. (Continued)

Baseflow Date	5-Day BOD	Ammo-nia	Nitrate + Nitrite	Ortho-phos-phate	TKN	Total P	TSS	Copper (µg/l)	Lead (µg/l)	Zinc (µg/l)	TPH	*E. coli* (MPN/ 100 ml)	Total Nitro-gen	Hard-ness	Chlor-ide	Turbid-ity (NTU)
Station WC004																
7/15/2021	<1	0.09	1.8	<0.05	0.8	0.02	<2	0.5	0.08	12	<5	411.0	2.6	172	161.0	1.06
8/5/2021	<1	0.10	1.5	<0.05	0.5	0.02	4	1.0	<1.00	11	<5	308.0	2.0	192	164.0	1.45
9/13/2021	<1	<0.30	1.7	<0.05	0.4	0.02	<2	0.8	<1.00	12	<5	140.0	2.1	226	198.0	0.48
10/8/2021	<1	0.08	3.1	<0.05	0.5	0.05	4	2.0	0.50	22	<5	488.0	3.6	343	318.0	1.06
11/18/2021	<1	0.06	2.9	<0.05	0.9	<0.05	<2	2.0	0.20	21	<5	62.0	3.8	326	346.0	0.20
12/9/2021	<1	0.07	3.5	<0.05	0.6	<0.05	<2	<2.0	<1.00	20	<5	9.6	4.1	748	324.0	0.28
1/13/2022	<1	0.05	2.9	0.01	0.6	0.03	5	3.0	1.00	33	<5	51.2	3.5	332	342.0	1.64
2/22/2022	<1	0.07	3.0	<0.05	0.6	0.01	<2	1.0	<1.00	31	<5	52.0	3.6	320	473.0	0.32
3/23/2022	1	<0.30	3.3	<0.05	0.9	0.02	8	<2.0	<1.00	23	<5	12.2	4.2	330	113.0	1.23
4/25/2022	1	<0.30	2.8	<0.05	0.6	<0.05	4	<2.0	<1.00	22	<5	47.1	3.4	326	403.0	0.51
5/10/2022	<1	<0.30	2.4	<0.05	0.7	0.02	<3	2.0	<1.00	21	<5	63.1	3.1	200	280.0	0.55
6/15/2022	<1	<0.30	1.3	<0.05	1.9	0.25	<3	<2.0	0.40	15	<5	687.0	3.2	180	170.0	1.07

4.3 BASEFLOW MEAN AND STORM EVENT MEAN CONCENTRATION DATA

EMC values for each parameter were calculated at each station for each storm event (Table 4-3). Average annual baseflow concentration and storm EMC values were calculated for each pollutant at each station (Table 4-4). Average concentration data computed for storm and baseflows over the course of a year were used to characterize pollutant concentrations during average baseflow conditions or an average stormflow event (Figures 4-1 through 4-6). Total annual and seasonal baseflow mean concentrations, storm EMCs, and loads for each pollutant are presented in Appendix D and Appendix E, respectively.

Under baseflow conditions, average concentrations of combined nitrate plus nitrite, TKN, total P, chloride, copper, lead, and zinc were highest at Station WC004 compared to the other two stations downstream (Figures 4-1 through 4-6). Concentrations of ammonia were disproportionally highest at Station WC002, 194.1% higher than the next highest mean concentration. The higher concentrations of *E. coli* and ammonia at Station WC002 may indicate a continued nutrient and septic input in the vicinity of the station. The excessive levels of ammonia at Station WC002 may indicate the presence of a chronic problem such as leakage from a sanitary sewage line. Higher average chloride values at Station WC004 may be the result of mobilization of chloride in groundwater as a result of runoff from legacy deicing compound application at the Festival of Bel Air Shopping Center and along Route 24. Samples collected at Station WC003 had the highest average concentrations of TSS during baseflow conditions, while Station WC002 samples had the highest average concentrations of BOD, ammonia, orthophosphate, and *E. coli* at baseflow conditions. Average baseflow concentrations of TPH were the same at all three stations.

Under stormflow conditions, average EMCs were highest at Station WC004 for BOD, ammonia, TKN, and zinc (Figures 4-1 through 4-6). Average EMCs for combined nitrate plus nitrite, orthophosphate, total P, TSS, copper, lead, and *E. coli* were highest at Station WC002. At Station WC003, the EMC for chloride was highest of the three stations. TPH was not recorded in any of the stormflow samples. All average stormflow EMCs exceeded corresponding baseflow mean concentrations at all stations except combined nitrate plus nitrite (all three stations), chloride (Station WC004 only), and ammonia (Station WC002). Average EMCs of all pollutants at all stations were lower than Maryland and national average values (Table 4-4).

Time-series plots of the annual average pollutant concentrations measured from 2010 to FY2022 are shown in Figure 4-7 through Figure 4-15, illustrating the change, on an annual basis, in pollutant concentrations as restoration projects were implemented in the watershed. Plots of average annual storm EMCs and baseflow MCs (with individual non-detect concentrations set to zero) are presented for the following pollutants: nitrate-nitrite, TKN, total phosphorus, TSS, copper, zinc, lead, ammonia, and BOD. Note that data from the shortened reporting period comprising the first six months of calendar year 2015 were not included in the plots.

Table 4-3. Storm event mean concentration results (mg/L except where indicated), July 2021 – June 2022 (non-detects set to zero).

Storm Date	Rainfall (inches)	5-Day BOD	Ammonia	Nitrate + Nitrite	Orthophos-phate	TKN	Total P	TSS	Chloride	Copper (µg/l)	Lead (µg/l)	Zinc (µg/l)
Station WC002												
6/30/2021	1.07	0.54	0.00	1.37	0.03	0.68	0.02	0.00	80.10	3.55	0.18	7.20
8/19/2021	0.18	1.96	0.12	0.70	0.02	0.85	0.09	22.51	97.81	5.99	1.00	5.85
9/3/2021	4.30	2.81	0.06	0.40	0.05	1.12	0.21	53.68	27.78	13.50	2.63	38.13
12/13/2021	0.14	2.34	0.00	1.07	0.00	0.70	0.04	10.01	115.32	4.67	0.10	15.67
1/10/2022	0.25	2.37	0.22	0.70	0.02	0.95	0.06	11.20	837.02	4.96	0.48	38.85
1/20/2022	0.46	2.59	0.15	0.56	0.03	0.75	0.07	14.38	193.46	7.32	0.80	24.71
3/10/2022	0.38	2.25	0.08	0.91	0.01	0.78	0.04	7.22	201.97	3.99	0.26	17.32
5/9/2022	2.95	1.98	0.02	0.35	0.03	1.02	0.08	10.42	25.54	8.45	0.61	19.93
5/19/2022	0.34	4.88	0.37	0.75	0.01	1.37	0.08	25.23	66.17	3.44	0.56	21.78
Station WC003												
6/30/2021	1.07	3.28	0.07	0.44	0.02	1.17	0.04	6.11	62.58	6.39	0.81	15.35
8/19/2021	0.18	1.11	0.10	0.48	0.00	1.10	0.08	6.15	111.27	3.18	0.13	6.55
9/3/2021	4.30	1.96	0.06	0.30	0.05	0.95	0.10	28.97	38.47	2.50	0.27	9.02
12/13/2021	0.14	2.00	0.00	0.90	0.00	0.74	0.05	15.81	165.52	5.09	0.45	24.55
1/10/2022	0.25	1.64	0.17	0.55	0.02	0.80	0.05	11.31	633.67	3.81	0.35	33.43
1/20/2022	0.46	2.70	0.18	0.44	0.02	0.76	0.06	11.39	253.29	4.39	0.54	22.64
3/10/2022	0.38	2.72	0.07	0.63	0.02	0.87	0.04	13.90	321.86	4.45	0.51	18.78
5/9/2022	2.95	2.03	0.06	0.31	0.01	1.14	0.08	10.49	59.91	8.65	0.97	25.10
5/19/2022	0.34	2.66	0.21	0.51	0.00	1.16	0.04	9.23	95.67	2.59	0.35	15.94
Station WC004												
6/30/2021	1.07	2.24	0.00	0.29	0.00	1.10	0.02	0.00	23.26	5.33	0.61	19.53
8/19/2021	0.18	8.61	0.06	0.19	0.00	0.84	0.05	12.55	86.99	9.08	1.41	21.38
9/3/2021	4.30	0.99	0.00	0.12	0.08	0.51	0.05	8.80	4.96	4.96	0.68	14.40
12/13/2021	0.14	1.46	0.31	0.96	0.00	0.89	0.04	6.17	88.24	4.94	0.39	23.67
1/10/2022	0.25	2.56	0.22	0.33	0.03	0.97	0.06	9.71	562.07	4.68	0.64	50.32
1/20/2022	0.46	2.95	0.11	0.35	0.03	0.72	0.05	7.48	289.46	2.33	0.41	28.62
3/10/2022	0.38	3.51	0.11	0.68	0.02	1.19	0.05	8.63	402.70	5.38	0.57	32.10
5/9/2022	2.95	1.43	0.05	0.28	0.02	1.10	0.06	6.77	29.17	6.56	0.63	24.87
5/19/2022	0.34	4.62	0.36	0.63	0.01	1.66	0.07	19.00	61.29	5.56	0.82	30.13

Table 4-4. Average storm EMCs and baseflow mean concentrations, Wheel Creek Watershed, July 2021 – June 2022 (non-detects set to zero). All concentrations are in units of mg/L unless indicated.

Station	5-Day BOD	Ammonia	Nitrate + Nitrite	Ortho-phos-phate	TKN	Total P	TSS	Chlor-ide	Copper (µg/l)	Lead (µg/l)	Zinc (µg/l)	TPH	*E. coli* (MPN/ 100 ml)
Storm Event Mean Concentrations													
WC002	2.41	0.11	0.76	0.02	0.91	0.08	17.18	182.80	6.21	0.74	21.05	0.00	1,239.56
WC003	2.23	0.10	0.51	0.01	0.97	0.06	12.60	193.58	4.56	0.49	19.04	0.00	1,002.70
WC004	3.15	0.14	0.43	0.02	1.00	0.05	8.79	172.02	5.42	0.68	27.22	0.00	929.26
MD avg[a]	14.44	N.R.	0.85	N.R.	1.94	0.33	66.57	N.R.	17.9	12.5	143.3	N.R.	N.R.
NSQD[b]	16.943	N.R.	1.587	N.R.	2.921	0.412	111.295	N.R.	42	41	250	2.759	N.R.
NURP[c]	9	N.R.	0.68	N.R.	1.5	0.33	100	N.R.	34	144	160	N.R.	N.R.
Baseflow Mean Concentrations													
WC002	0.33	0.27	1.28	0.00	0.60	0.02	3.58	142.13	0.26	0.04	10.00	0.00	378.85
WC003	0.17	0.10	0.92	0.00	0.61	0.01	4.67	167.86	0.73	0.05	10.25	0.00	240.82
WC004	0.17	0.04	2.52	0.00	0.75	0.04	2.08	274.33	1.03	0.18	20.25	0.00	194.27

N.R. = Reference data not available.
[a] = Maryland State average values from Bahr 1997.
[b] = National Stormwater Quality Database values for Maryland from Pitt 2008.
[c] = National Urban Runoff Program values from U.S. EPA 1983.

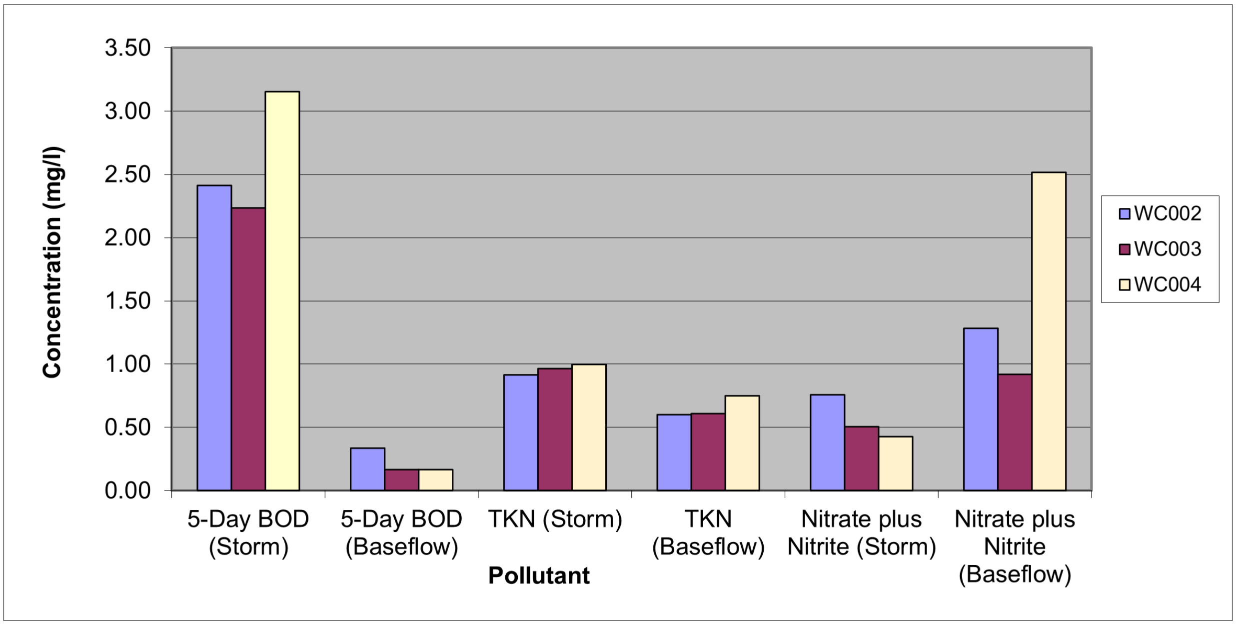

Figure 4-1. Nitrogen and 5-day BOD average storm event mean and baseflow mean concentrations in Wheel Creek, July 2021 – June 2022

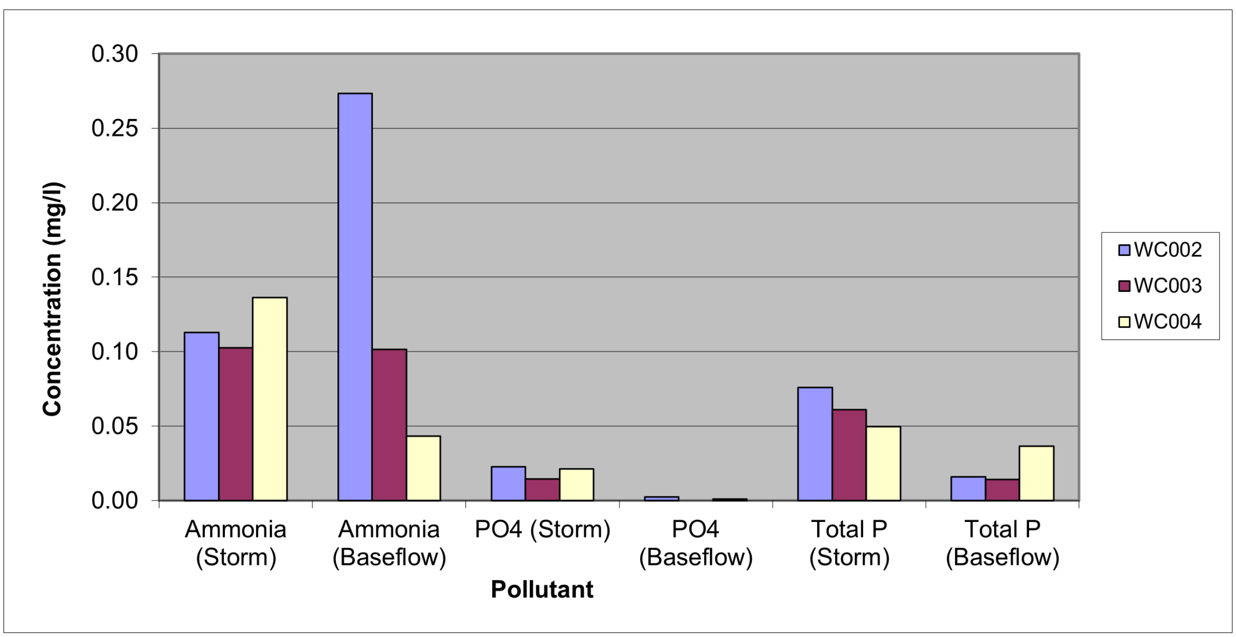

Figure 4-2. Ammonia and phosphorus average storm event mean and baseflow mean concentrations in Wheel Creek, July 2021 – June 2022

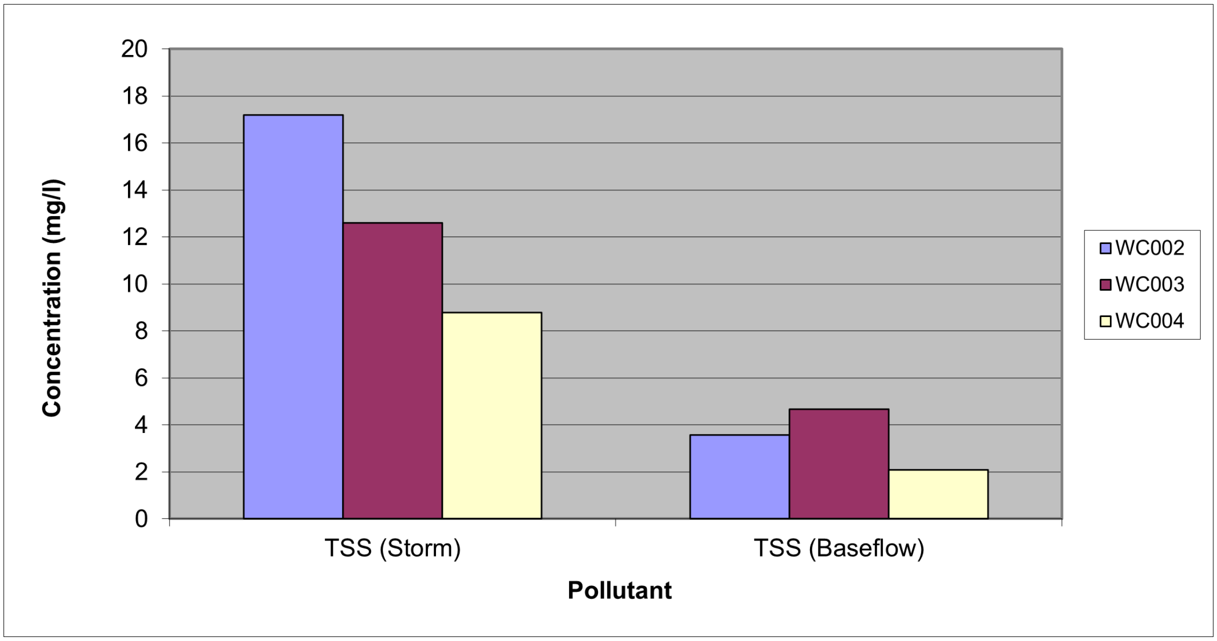

Figure 4-3. TSS average storm event and baseflow mean concentrations in Wheel Creek, July 2021 – June 2022

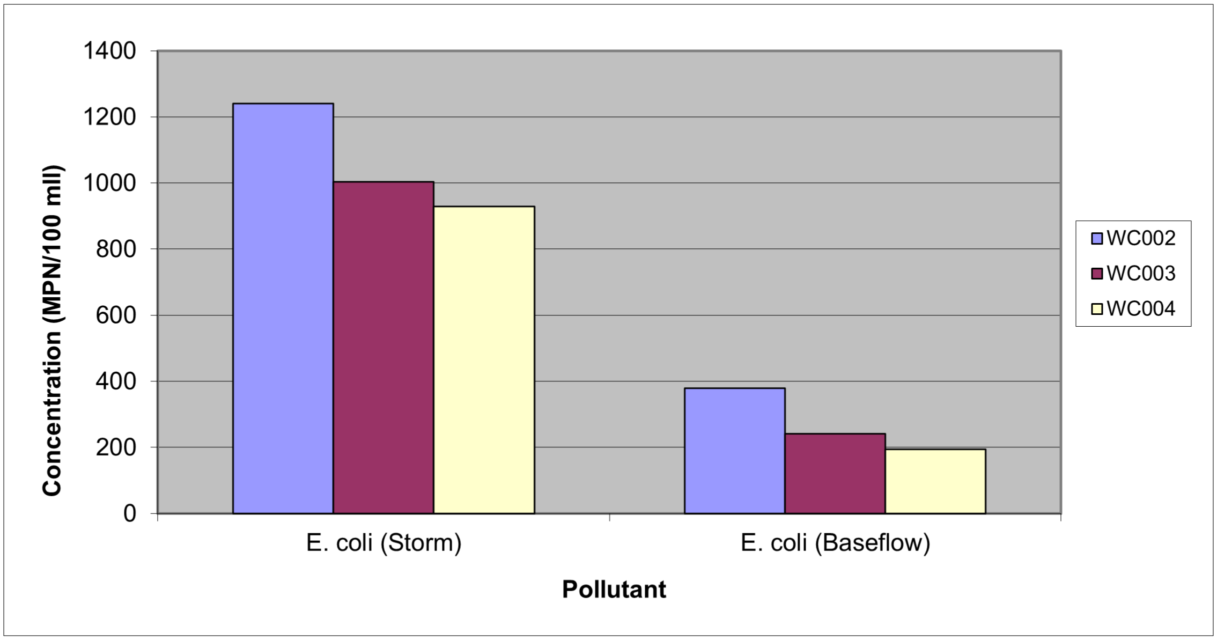

Figure 4-4. *E. coli* average storm and baseflow mean concentrations in Wheel Creek, July 2021 – June 2022

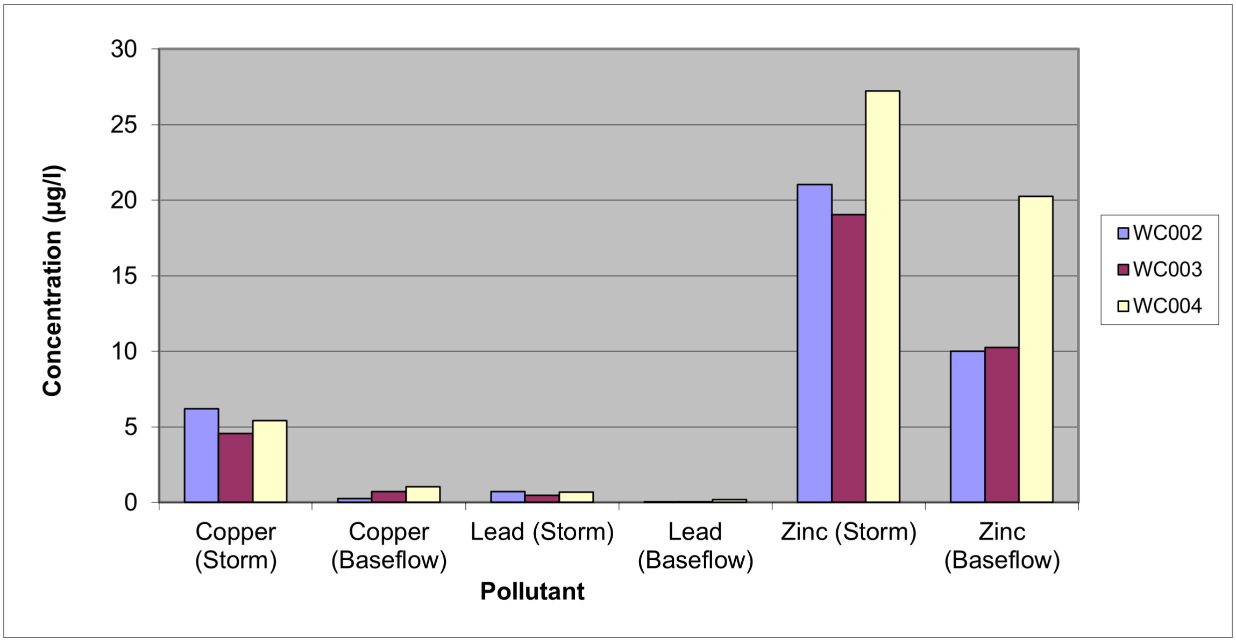

Figure 4-5. Metal average storm event mean and baseflow mean concentrations in Wheel Creek, July 2021 – June 2022

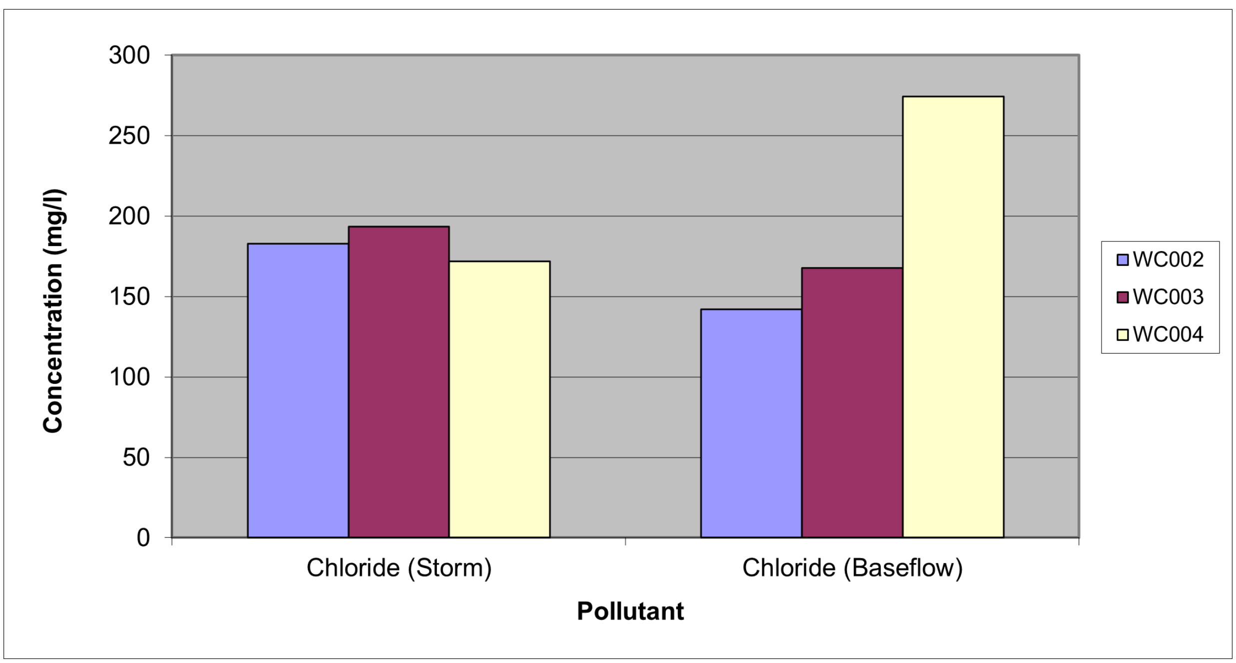

Figure 4-6. Chloride average storm event mean and baseflow mean concentrations in Wheel Creek, July 2021 – June 2022

Visually, some of the plots show a potential change in long-term trend in annual concentration data that can be associated with completion of restoration projects in the watershed. For nitrate plus nitrite through FY2022, the prevailing trend continues gradually downward at all stations since approximately 2014, although there was a slight increase in FY2022 stormflow EMCs, coinciding with the completion of most of the restoration projects. Storm EMCs for several of the parameters, such as total phosphorus, TSS, copper, and BOD show signs of gradually increasing trend until approximately FY2017 and then notably falling in FY2018 through FY2020. All four of these constituents showed signs of an increasing trend again in FY2021, but the trend was reversed overall for these four constituents in FY2022 with the exception of stormflow BOD EMC at Station WC004. Average storm EMCs for TKN behaved similarly in FY2018 but rebounded in FY2019 through FY2022 at all stations; although Station WC002 showed a decreasing trend between FY2021 and FY2022, the overall trend at this station is still increasing since FY2019. Similarly, EMCs for ammonia gradually decreased through FY2017, from which point there has been variability in average storm EMCs and baseflow MCs but still an increasing trend through FY2022. Lead EMCs for two out of three stations declined in FY2019 and FY2020 but increased for two of the three stations in FY2021; these two EMCs decreased in FY2022 while the remaining EMC (Station WC004) increased in FY2022. Zinc EMCs declined at all three stations in FY2020 compared to the previous year and continued this trend in FY2021 except for Station WC003 which showed a slight increase in average storm EMC; zinc EMCs at all three stations continued the negative trend in FY2022. The time series data may indicate that the restoration efforts, in concert, are having the desired effect of reducing parameters under specific flow regimes except for ammonia, total phosphorus, and TKN. Continued monitoring is recommended to distinguish a permanent change in long-term pollutant concentrations.

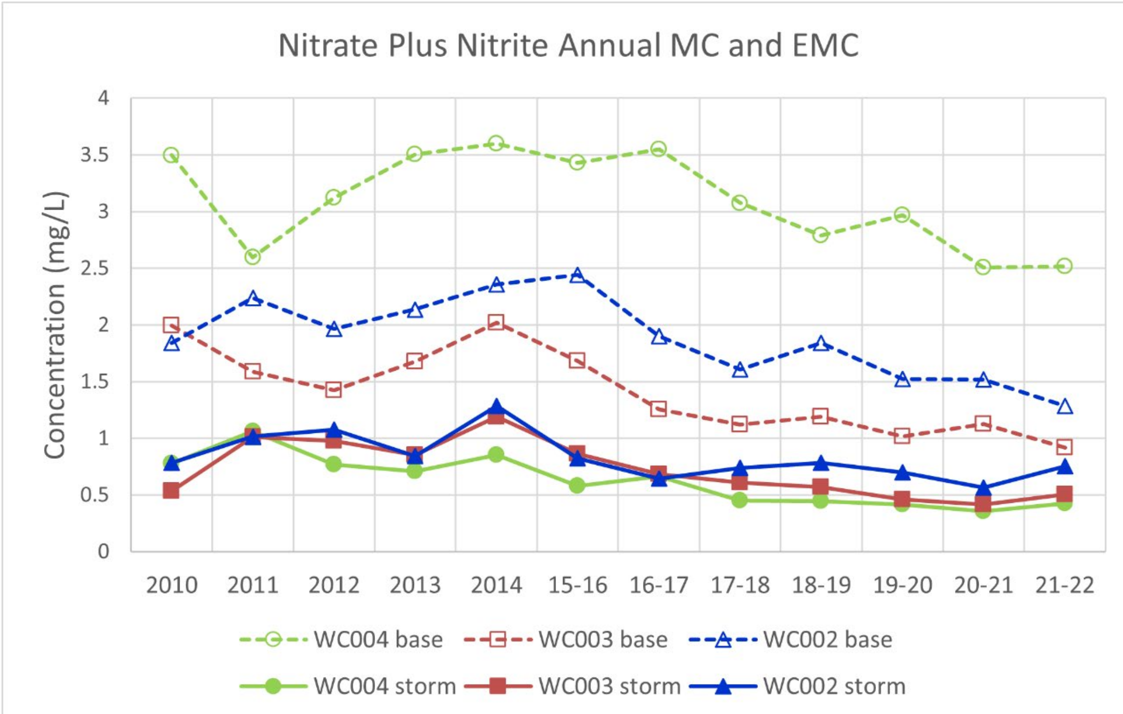

Figure 4-7. Time series plot of average annual baseflow MC and stormflow EMC for nitrate-nitrite (2010-FY2022)

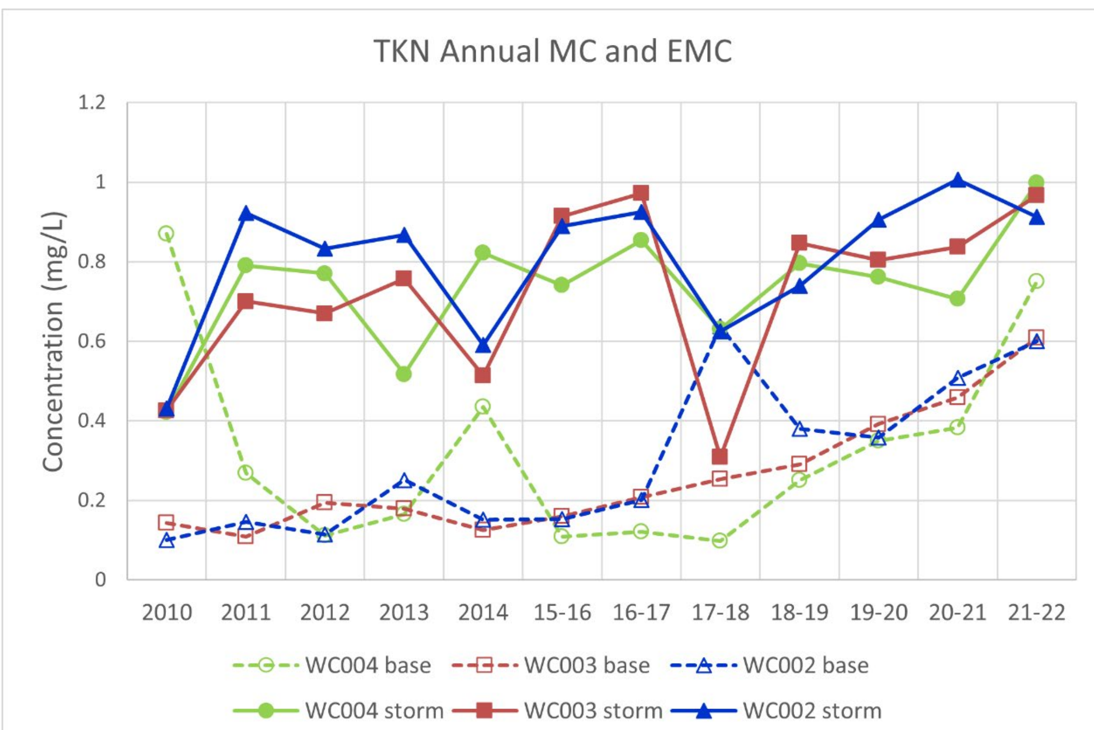

Figure 4-8. Time series plot of average annual baseflow MC and stormflow EMC for TKN (2010-FY2022)

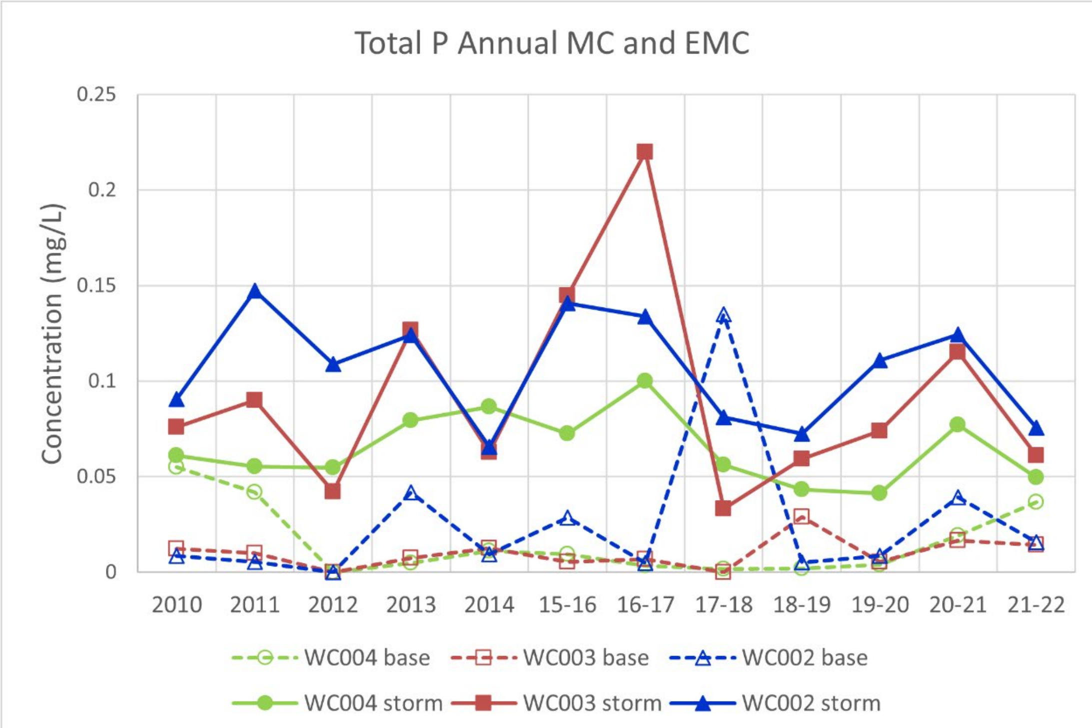

Figure 4-9. Time series plot of average annual baseflow MC and stormflow EMC for total phosphorus (2010-FY2022)

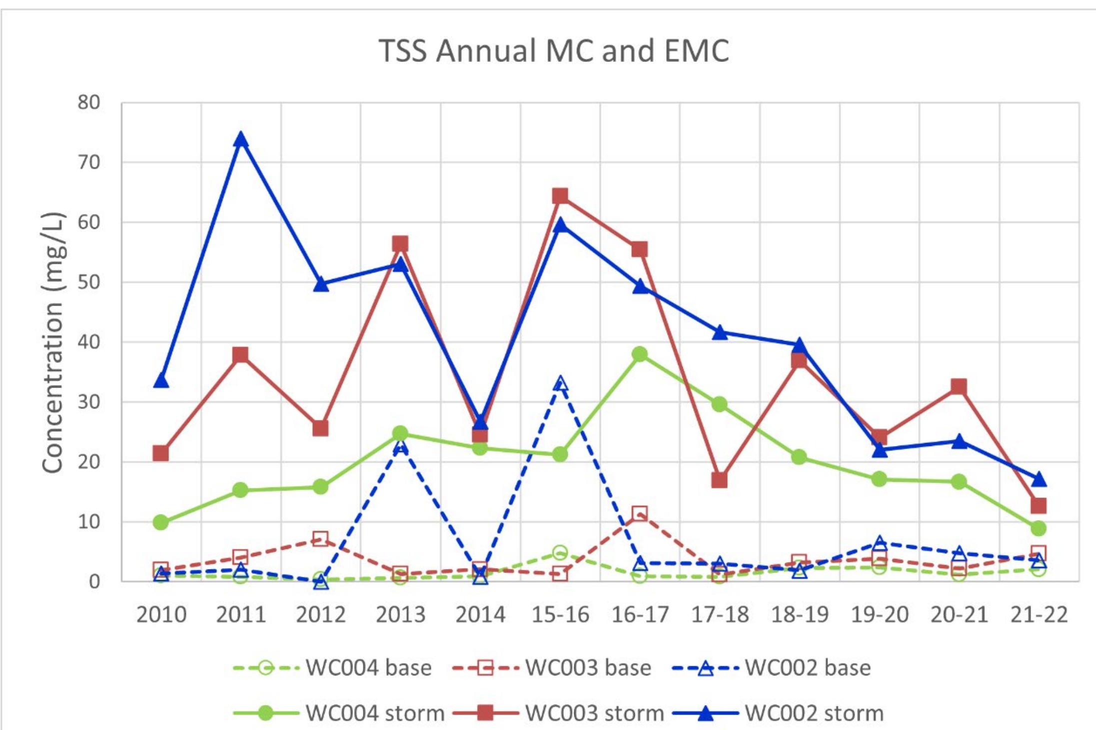

Figure 4-10. Time series plot of average annual baseflow MC and stormflow EMC for TSS (2010-FY2022)

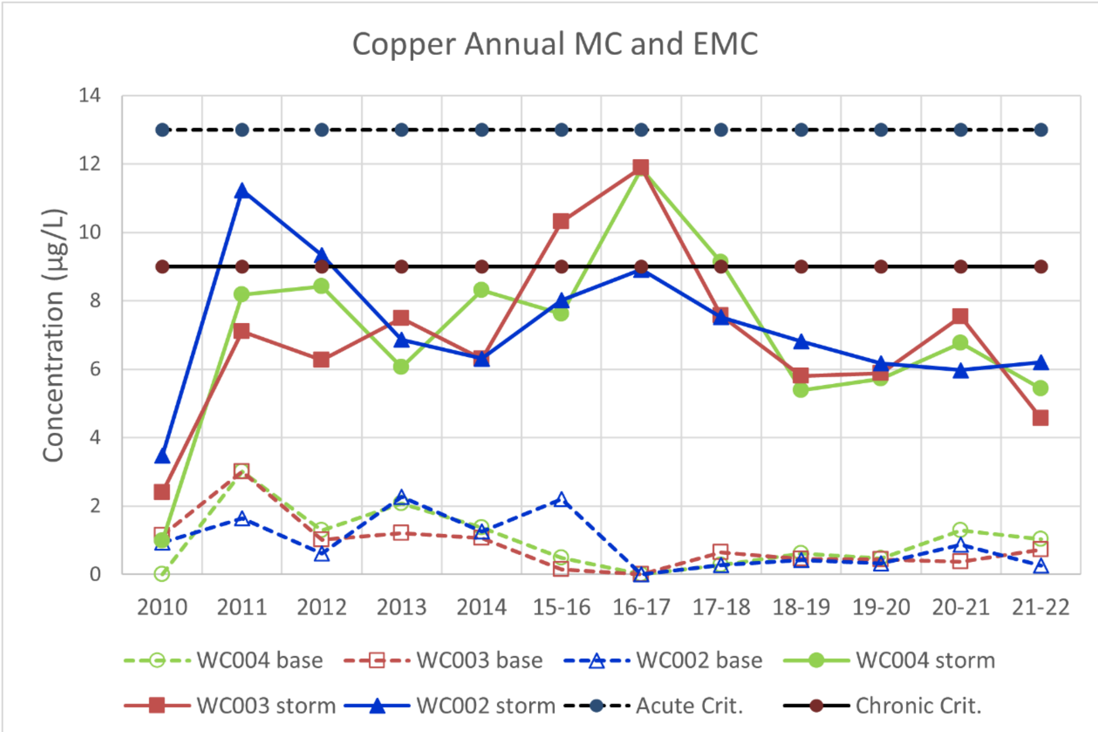

Figure 4-11. Time series plot of average annual baseflow MC and stormflow EMC for copper (2010-FY2022)

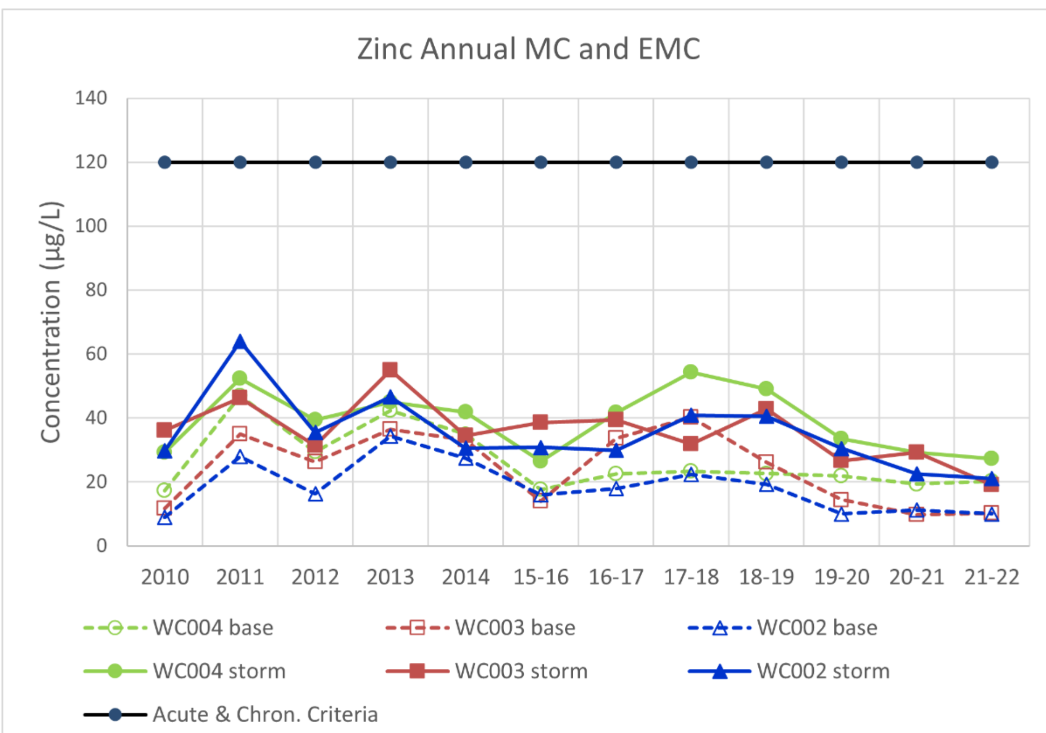

Figure 4-12. Time series plot of average annual baseflow MC and stormflow EMC for zinc (2010-FY2022)

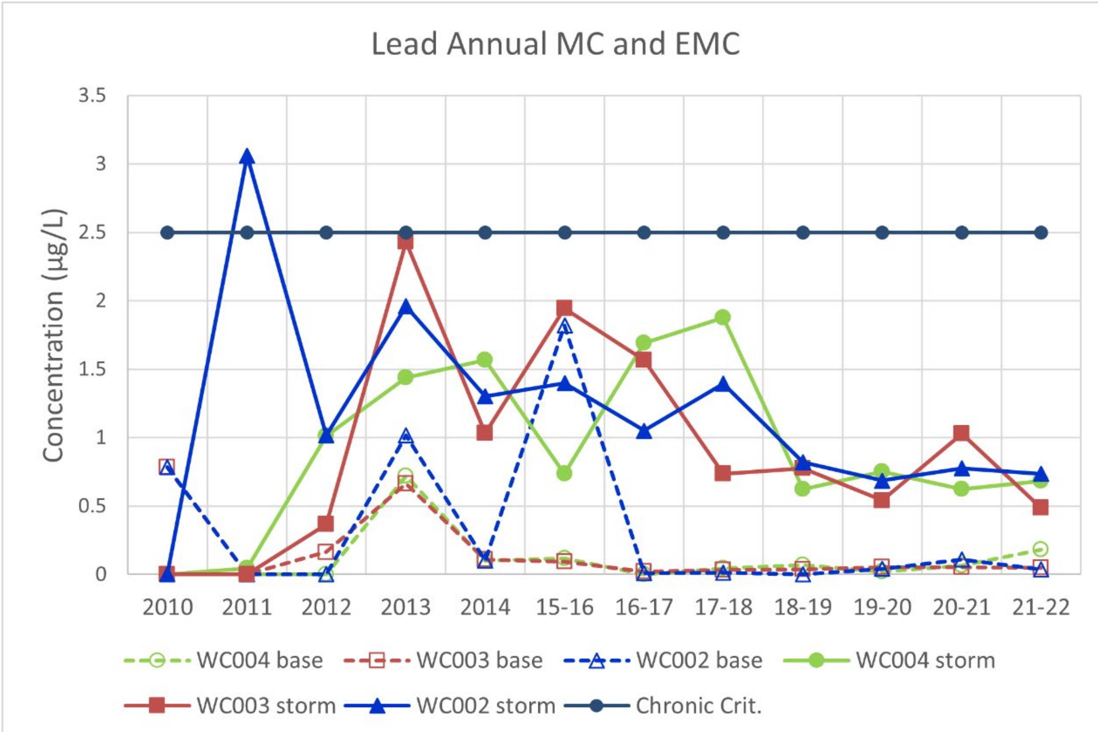

Figure 4-13. Time series plot of average annual baseflow MC and stormflow EMC for lead (2010-FY2022). Note: the acute criterion is not shown to maintain small scale.

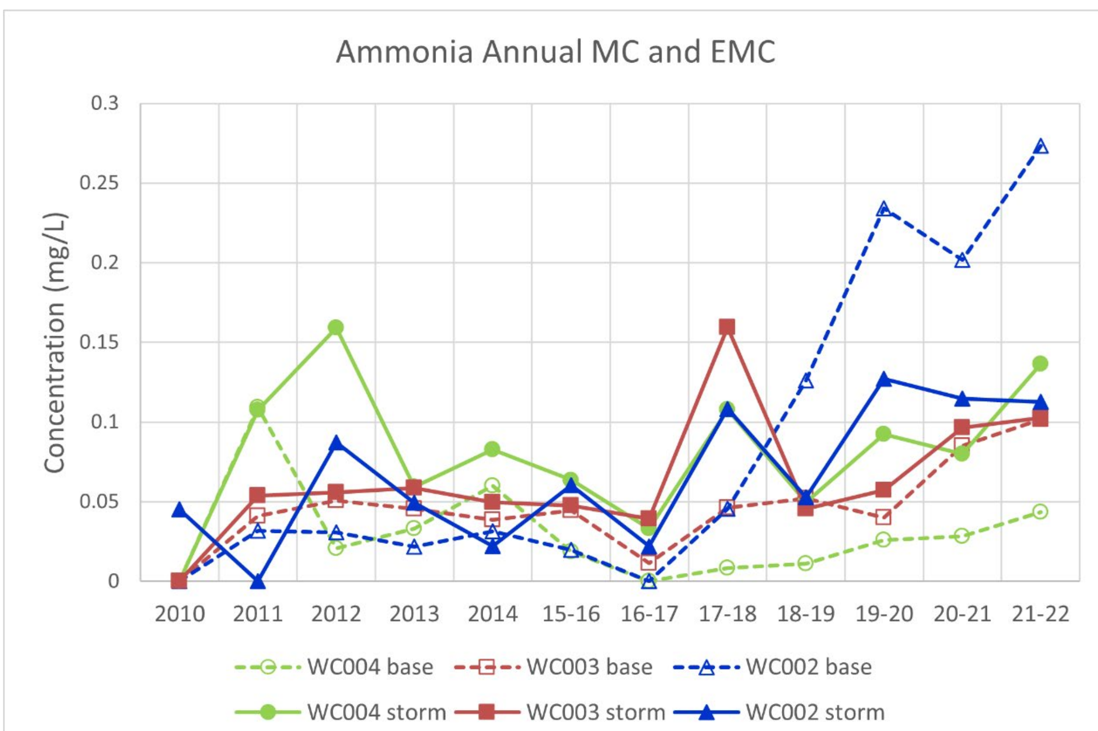

Figure 4-14. Time series plot of average annual baseflow MC and stormflow MC for ammonia (2010-FY2022)

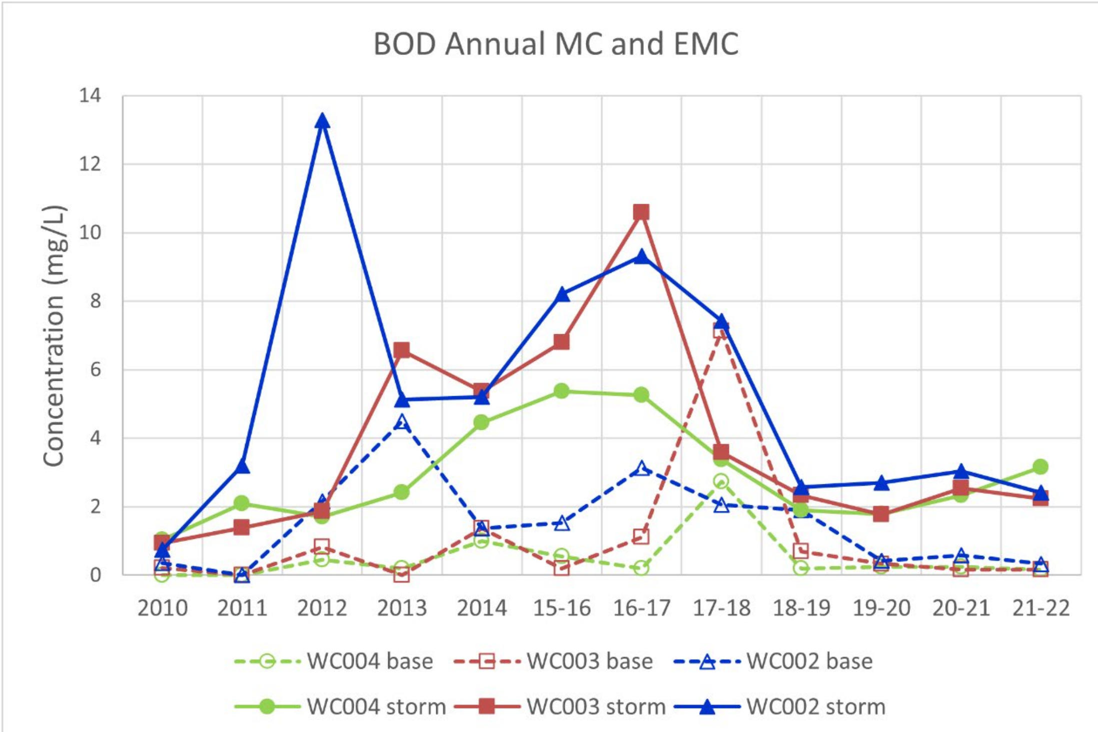

Figure 4-15. Time series plot of average annual baseflow MC and stormflow MC for BOD (2010-FY2022)

4.4 STORMFLOW POLLUTANT LOADING DATA

Pollutant loads for individual storms at each station were calculated from individual stormflow event mean concentration data (Table 4-5). Pollutant load represents the quantity of pollutant, in pounds, that was transported in the stream during the event. For discussion purposes, an average load was determined for each pollutant at each station for storms monitored from July 2021 through June 2022. Since the final wet weather event of FY2021 initiated on June 30, 2021 but continued until July 2, 2021, average load results in this report include this result in the Year 12 report.

When comparing stations, average storm loads were highest at Station WC002 for all parameters (Table 4-6). Average loads were lowest at Station WC004 for all parameters. Since discharge volume for a given storm increases with distance downstream, maximum load results at Station WC002 are expected.

Table 4-5. Storm event pollutant loadings (lbs per event), July 2021 – June 2022 (non-detects set to zero).

Storm Date	Discharge (cf)	5-Day BOD	Ammonia	Nitrate + Nitrite	Ortho-phosphate	TKN	Total P	TSS	Chloride	Copper	Lead	Zinc
Station WC002												
6/30/2021	563,384	18.89	0.00	48.11	1.18	24.07	0.68	0.00	2,817.28	0.125	0.006	0.253
8/19/2021	98,499	12.03	0.74	4.33	0.12	5.22	0.57	138.41	601.42	0.037	0.006	0.036
9/3/2021	3,958,360	693.43	14.32	99.24	11.16	275.75	51.16	13,265.00	6,865.15	3.335	0.651	9.423
12/13/2021	65,437	9.54	0.00	4.36	0.01	2.86	0.16	40.88	471.11	0.019	0.000	0.064
1/10/2022	167,887	24.80	2.30	7.32	0.23	9.92	0.59	117.40	8,772.70	0.052	0.005	0.407
1/20/2022	179,269	28.97	1.66	6.25	0.32	8.43	0.80	160.97	2,165.14	0.082	0.009	0.277
3/10/2022	137,856	19.40	0.67	7.82	0.13	6.69	0.32	62.17	1,738.20	0.034	0.002	0.149
5/9/2022	1,650,110	203.67	2.35	35.93	2.79	105.51	7.98	1,072.96	2,631.38	0.870	0.063	2.054
5/19/2022	94,034	28.68	2.16	4.38	0.07	8.02	0.48	148.10	388.45	0.020	0.003	0.128
Station WC003												
6/30/2021	364,297	74.71	1.53	9.96	0.34	26.57	0.96	138.92	1,423.21	0.145	0.018	0.349
8/19/2021	23,942	1.67	0.16	0.72	0.00	1.65	0.12	9.19	166.32	0.005	0.000	0.010
9/3/2021	1,624,760	199.14	6.13	30.43	5.22	96.72	10.53	2,938.25	3,902.43	0.254	0.028	0.915
12/13/2021	3,843	0.48	0.00	0.22	0.00	0.18	0.01	3.79	39.71	0.001	0.000	0.006
1/10/2022	62,421	6.37	0.66	2.12	0.06	3.11	0.18	44.07	2,469.29	0.015	0.001	0.130
1/20/2022	112,979	19.01	1.29	3.11	0.13	5.35	0.39	80.35	1,786.47	0.031	0.004	0.160
3/10/2022	54,502	9.27	0.22	2.14	0.06	2.97	0.15	47.29	1,095.13	0.015	0.002	0.064
5/9/2022	653,446	82.64	2.42	12.67	0.47	46.44	3.30	428.00	2,443.83	0.353	0.040	1.024
5/19/2022	62,645	10.39	0.83	2.00	0.00	4.55	0.17	36.09	374.15	0.010	0.001	0.062
Station WC004												
6/30/2021	123,776	17.31	0.00	2.26	0.01	8.48	0.19	0.00	179.74	0.041	0.005	0.151
8/19/2021	14,803	7.96	0.06	0.18	0.00	0.78	0.05	11.60	80.39	0.008	0.001	0.020
9/3/2021	767,673	47.36	0.00	5.59	3.79	24.53	2.38	421.69	237.51	0.238	0.033	0.690
12/13/2021	5,972	0.54	0.12	0.36	0.00	0.33	0.01	2.30	32.90	0.002	0.000	0.009
1/10/2022	20,949	3.34	0.29	0.43	0.03	1.27	0.07	12.70	735.07	0.006	0.001	0.066
1/20/2022	43,316	7.99	0.30	0.93	0.07	1.96	0.13	20.23	782.74	0.006	0.001	0.077
3/10/2022	22,292	4.89	0.16	0.94	0.02	1.65	0.07	12.01	560.41	0.007	0.001	0.045
5/9/2022	196,529	17.60	0.55	3.46	0.30	13.46	0.68	83.03	357.86	0.081	0.008	0.305
5/19/2022	24,330	7.01	0.54	0.96	0.02	2.52	0.10	28.86	93.10	0.008	0.001	0.046

Table 4-6. Average storm pollutant loads (lbs/event), Wheel Creek monitoring, July 2021 – June 2022 (non-detects set to zero)

Station	5-Day BOD	Ammonia	Nitrate + Nitrite	Ortho-phosphate	TKN	Total P	TSS	Chloride	Copper	Lead	Zinc
WC002	115.49	2.69	24.19	1.78	49.61	6.97	1,667.32	2,938.98	0.508	0.083	1.421
WC003	44.85	1.47	7.04	0.70	20.84	1.76	414.00	1,522.28	0.092	0.010	0.302
WC004	12.67	0.22	1.68	0.47	6.11	0.41	65.82	339.97	0.044	0.006	0.156

4.5 SEDIMENT TRANSPORT SAMPLING RESULTS

A summary of suspended sediment transport data for Stations WC002, WC003, and WC004 (Tables 4-7 through 4-9) and suspended sediment transport curves for Stations WC002, WC003, and WC004 (Figures 4-16 through 4-18) are presented below. The discharges associated with each sediment sample were approximated from flow rate data recorded at the time when the stage at which the samplers filled, as shown by stage loggers attached to the siphon samplers, was achieved.

Nine storm events were sampled from July 2021 to June 2022; due to the overlap between fiscal years and the final sampling event on June 30, 2021, suspended sediment concentrations from this event are presented in this report. From these nine storms with concentration data from FY2022, a total of 28 samples were collected at Station WC002 (Table 4-7), 25 samples were collected at Station WC003 (Table 4-8), and 17 samples were collected at Station WC004 (Table 4-9). Note that bottles are numbered in sequence from the lowest to the highest point in the water column. Suspended sediment concentrations ranged from 0.7 to 568.0 mg/L at Station WC002, 3.3 to 862.0 mg/L at Station WC003, and 2.6 to 153.0 mg/L at Station WC004.

Table 4-7. Suspended sediment results at Station WC002, July 2021 – June 2022

Date	Bottle Number	Suspended Sediment (mg/L)	Discharge (cfs)	Date	Bottle Number	Suspended Sediment (mg/L)	Discharge (cfs)
2-Jul-21	1	50.0	0.95	10-Jan-22	1	4.4	1.27
2-Jul-21	2	28.9	1.19	20-Jan-22	1	7.8	1.38
2-Jul-21	3	155.0	3.70	20-Jan-22	3	21.8	N.R.
2-Jul-21	4	403.0	15.91	10-Mar-22	1	4.9	1.01
2-Jul-21	5	228.0	38.48	10-Mar-22	2	568.0	2.76
18-Aug-21	1	5.0	1.57	9-May-22	1	58.3	4.63
5-Sep-21	1	106.0	1.87	9-May-22	2	72.9	4.63
5-Sep-21	2	241.0	1.87	9-May-22	3	53.6	4.63
5-Sep-21	3	360.0	21.05	9-May-22	4	56.7	4.63
5-Sep-21	4	328.0	39.17	9-May-22	5	63.4	4.63
5-Sep-21	5	272.0	108.35	9-May-22	6	55.1	4.63
5-Sep-21	6	258.0	108.35	19-May-22	1	7.2	0.63
13-Dec-21	1	2.2	1.81	19-May-22	2	109.0	1.03
13-Dec-21	2	0.7	1.81	19-May-22	3	67.9	2.61

N.R. – Corresponding level data from logger and flow rate could not be determined for this sample.

Date	Bottle Number	Suspended Sediment (mg/L)	Discharge (cfs)	Date	Bottle Number	Suspended Sediment (mg/L)	Discharge (cfs)
2-Jul-21	1	13.8	0.57	10-Jan-22	1	14.3	0.97
2-Jul-21	2	266.0	5.87	10-Jan-22	2	16.6	N.R.
2-Jul-21	3	404.0	13.34	20-Jan-22	1	14.7	N.R.
2-Jul-21	4	426.0	N.R.	20-Jan-22	2	3.3	N.R.
18-Aug-21	1	19.0	0.37	10-Mar-22	1	111.0	1.93
5-Sep-21	1	118.0	13.32	10-Mar-22	2	180.0	N.R.
5-Sep-21	2	410.0	136.99	9-May-22	1	66.8	3.54
5-Sep-21	3	728.0	196.83	9-May-22	2	127.0	3.54
5-Sep-21	4	862.0	N.R.	9-May-22	3	100.0	3.54
5-Sep-21	5	171.0	N.R.	9-May-22	4	110.0	7.04
5-Sep-21	6	206.0	N.R.	19-May-22	1	5.1	1.40
13-Dec-21	1	19.9	0.10	19-May-22	2	105.0	3.53
13-Dec-21	2	197.0	0.10				

Table 4-8. Suspended sediment results at Station WC003, July 2021 – June 2022

N.R. – Corresponding level data from logger and flow rate could not be determined for this sample.

Date	Bottle Number	Suspended Sediment (mg/L)	Discharge	Date	Bottle Number	Suspended Sediment (mg/L)	Discharge
2-Jul-21	1	89.7	3.87	13-Dec-21	1	2.6	N.R.
2-Jul-21	2	21.1	N.R.	10-Jan-22	1	12.3	N.R.
2-Jul-21	3	11.7	N.R.	20-Jan-22	1	6.8	N.R.
5-Sep-21	1	153.0	N.R.	20-Jan-22	3	38.9	N.R.
5-Sep-21	2	67.4	N.R.	10-Mar-22	1	20.2	N.R.
5-Sep-21	3	86.1	N.R.	9-May-22	1	32.4	1.47
5-Sep-21	4	43.4	N.R.	9-May-22	2	27.6	1.43
5-Sep-21	5	76.3	N.R.	19-May-22	1	27.4	N.R.
5-Sep-21	6	93.1	N.R.				

Table 4-9. Suspended sediment results at Station WC004, July 2021 – June 2022

N.R. – Corresponding level data from logger and flow rate could not be determined for this sample.

Sediment transport curves were created for each station using concentrations of suspended sediment in samples and corresponding flow rate values for storms monitored from July 2021 through June 2022. Average instantaneous discharges for each sample were approximately the same as those reported in the previous year. Results at Station WC002 showed a low correlation between discharge and suspended sediment concentration ($r^2 = 0.355$; Figure 4-16). The sediment concentration correlation at Station WC002 was similar to that reported last year, but with lower concentrations per discharge noted. The sediment transport curve prepared for Station WC003 showed a moderate correlation between discharge and suspended sediment concentration (r^2 = 0.772; Figure 4-17). The sediment concentration correlation at Station WC003 was greater than that reported last year, but with lower concentrations per discharge noted. Results at Station WC004 showed a significant correlation between discharge and suspended sediment concentration (r^2 = 0.998; Figure 4-18); however, suspended sediment concentrations per discharge were only recorded in three samples at Station WC004 in FY2022 so this correlation is the result of an extremely small sample size and likely not a significant relationship.

The arithmetic mean of stormflow-associated suspended sediment concentrations, by station, exceeded corresponding average annual EMCs of TSS, suggesting that TSS results underestimate the actual transport of sediment during storms (Figure 4-19).

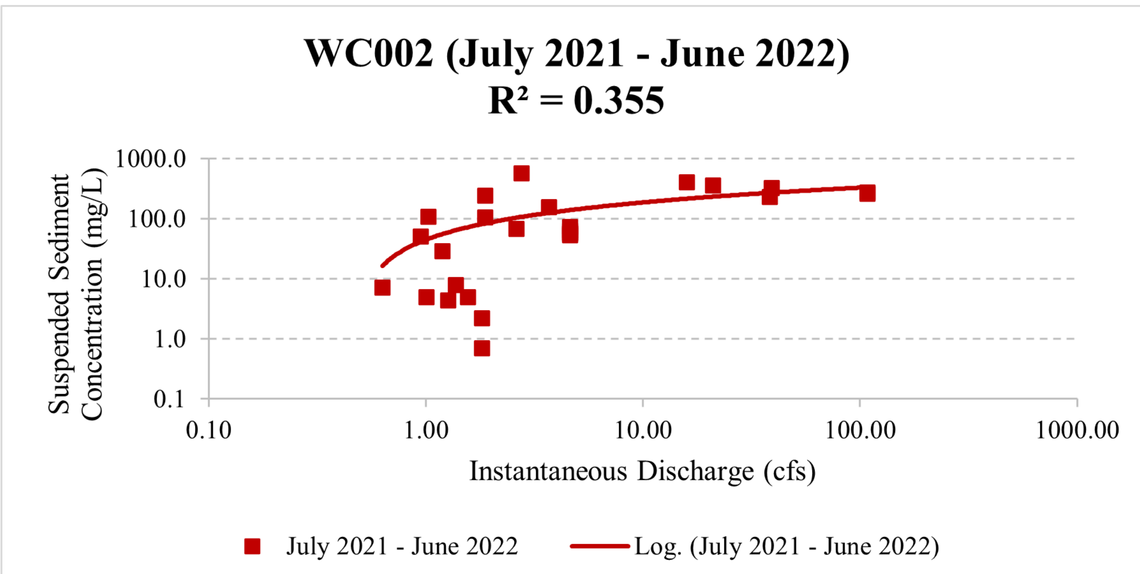

Figure 4-16. Suspended sediment curve for Wheel Creek Station 002 (July 2021 – June 2022)

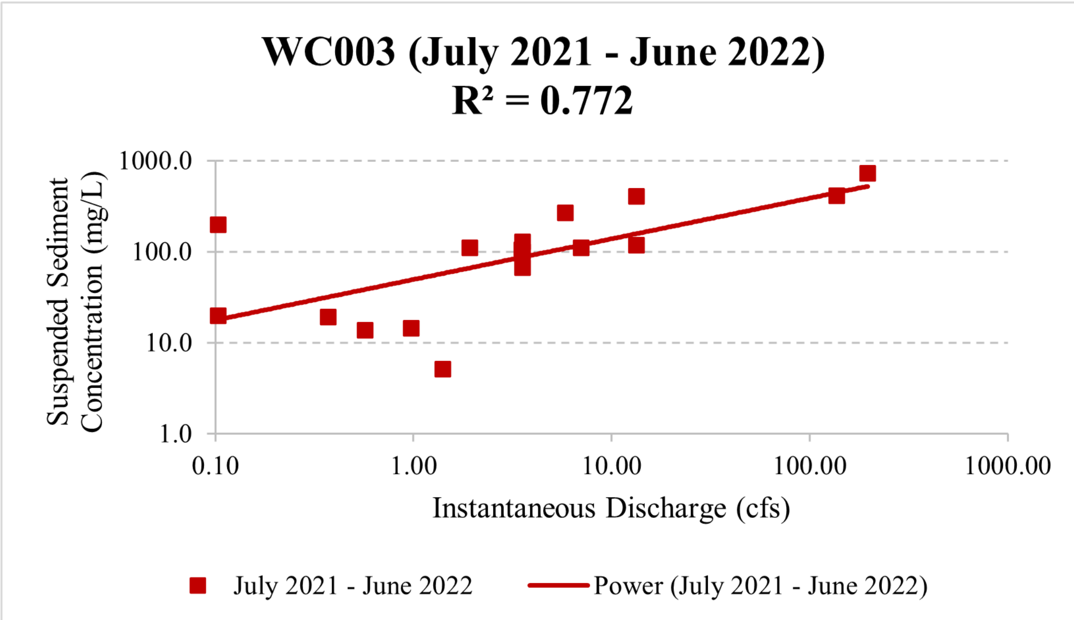

Figure 4-17. Suspended sediment curve for Wheel Creek Station 003 (July 2021 – June 2022)

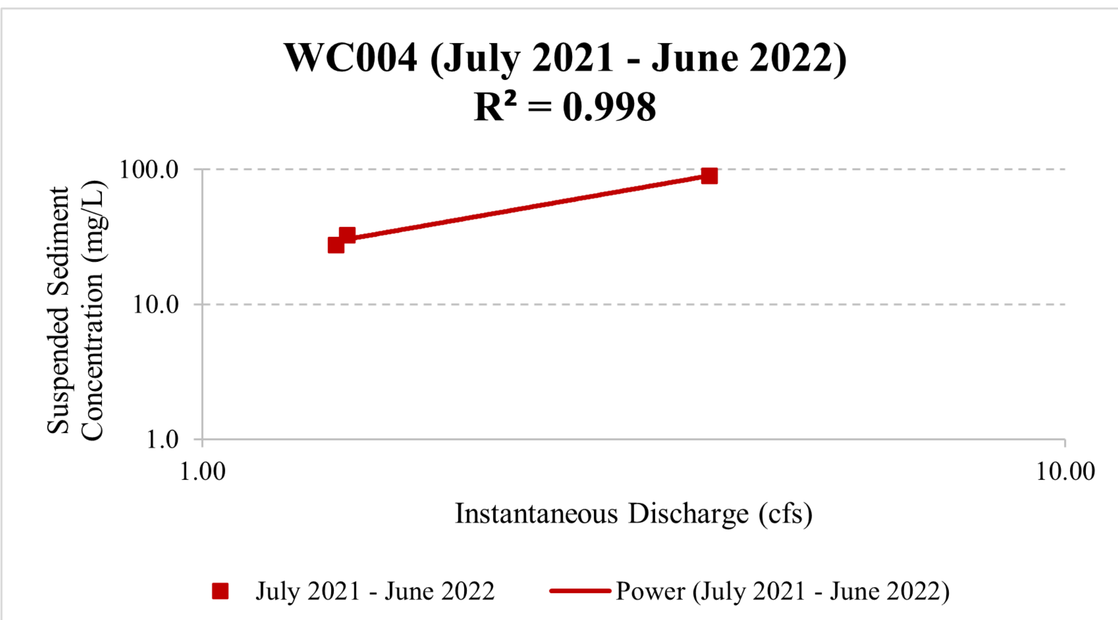

Figure 4-18. Suspended sediment curve for Wheel Creek Station 003 (July 2021 – June 2022)

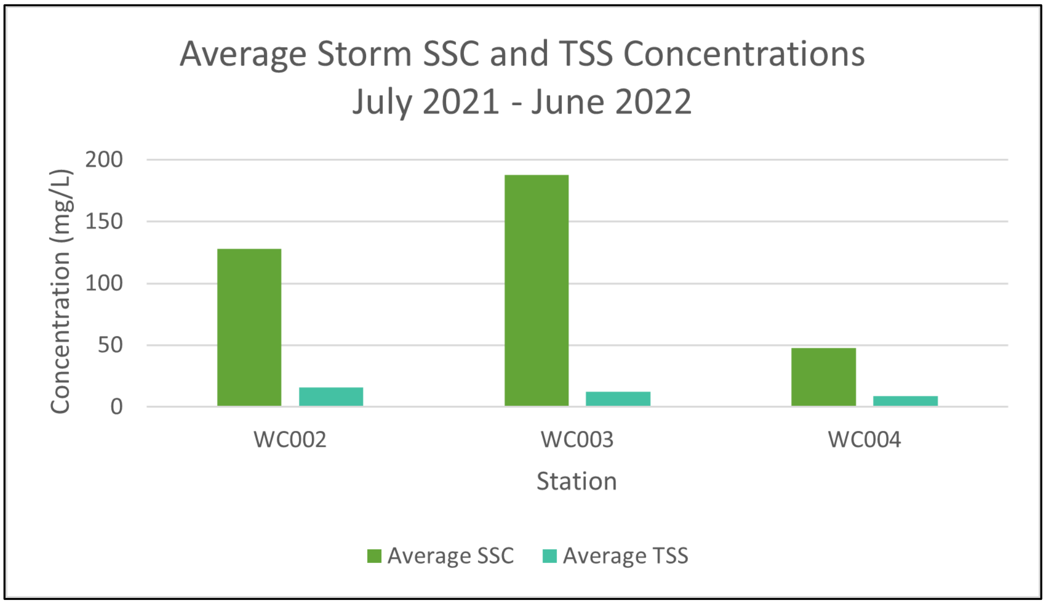

Figure 4-19. Average SSC and TSS concentrations in stormwater runoff (July 2021 – June 2022)

4.6 MONITORING PROBLEMS IDENTIFIED IN 2021-2022

4.6.1 Storm Events

During the June 30 – July 2, 2021 storm event, storm flow elevation continued beyond the anticipated program; therefore the field crew took falling grabs at all three sites during their respective composite times.

The August 16-17, 2021 and September 1-2, 2021 storm events consisted of precipitation that resulted in two peaks in stream discharge. Composites were prepared according to discharge volume per limb; rising and falling limbs were picked from portions of the storm that best represent those conditions, subject to availability of discrete samples.

The December 11-12, 2021 storm event was a minimal precipitation event, and there was a lot of noise in the flow rate data at this time, resulting in poor hydrographs at Stations WC002 and WC003.

The September 1-2, 2021 event was sampled during the Hurricane Ida storm event. The ISCO suction tubing detached at stations WC002 and WC003 after bottle 13, and a falling grab was obtained during the morning of 9/2/21 for all 3 stations. Both small sampler batteries died as well during the rain event at WC002 and WC003. Versar field crew noticed that a large tree fell at the WC004 station during the storm event. No County instrumentation was damaged during the tree fall but could experience an issue in the future with debris and erosion in and around the stream.

During the January 9-10, 2022 storm even, the ISCO suction tubing detached at Station WC002 and WC003 due to debris in the pipes. Versar field crew used the WC004 hydrograph to composite the storm for those sites.

During the January 20, 2022 storm event, the ISCO bubbler line detached from the sensor carrier at Station WC002 and WC003 stations during the storm event due to debris in the pipe. Versar field crew used the WC004 hydrograph to composite the storm at both affected sites.

During the May 6, 2022 storm event, the Versar Rain Gauge had a clog in it during the storm so a neighborhood rain gauge was used for the complete rain fall total of the storm. The clog resulted in a trickle discharge being recorded, which is why the recorded rainfall shown in the hydrographs is less than the overall recorded for the event; the rest of the rainfall was recorded after flows normalized and the clog was cleared, and is not included in the storm hydrographs.

During the May 18-19, 2022 storm event, the ISCO bubbler line detached from the sensor carrier at Station WC002 and WC003 stations during the storm event due to debris in the pipe. Versar field crew used the WC004 hydrograph to composite the storm at both affected sites.

4.6.2 Continuous Stage Logging

The Solinst level loggers at each station were downloaded monthly. Episodes of sensor drift due to presence of sediment after storm flows and leaf debris in the fall have been noted. The level loggers occasionally accumulate sediment in the sensor holes, which needs to be removed. Leaf debris buildup in the channels causes a temporary backwater condition, causing heightened stage and artificially inflated flow rate readings. Adjustments to correct for the drift and leaf buildup were performed to improve the flow record.

At the beginning of September 2021, the three instream Solinst loggers all had an extreme, unexpected drop in battery level, due to age, and shut off. ISCO bubbler flowmeters were installed at each station once this failure was found and new replacement sensors were ordered; however, data gaps in stage resulted and these portions of data between sensor failure and flowmeter installation. In the winter, there were several months when the Solinst level loggers were removed from the stream due to cold weather and risk of damage to sensors from ice buildup. To reduce data gaps, ISCO bubbler flowmeters were installed at each site when the Solinst instruments were temporarily removed. Bubbler flowmeters are less prone to damage due to ice buildup around the sensor.

To account for data gaps, the following protocols were used to complete the stage records. All data from the Solinst level loggers were aggregated, and anomalous data encountered during data offloads and logger swapping were manually interpolated with the surrounding stage data. The level logger data were shifted to match observed actual staff gauge readings, and linear drift corrections were applied to correct periods of sensor drift. ISCO flowmeter data were also shifted to match staff gauge observations and Solinst level logger data; the ISCO level data were used when Solinst level loggers were offline. When needed, barometric pressure data from a nearby weather station were used for pressure compensations of the instream Solinst level loggers. If equipment failures occurred, stream level data were modeled using a regression to determine the relationship between stations to estimate flow rate and fill in any resultant data gaps.

4.7 COMPARISON OF PRE- AND POST-RESTORATION CONDITIONS

4.7.1 Comparison of Pollutant Ratios Between Stations WC002 and WC003

For this evaluation, a comparison of the ratios (in percent; see definition in section 3.9.1) of average pollutant concentrations and annual loads between Station WC003 and Station WC002 was employed to determine the benefit, in terms of pollution reduction, of restoration projects in the mainstem and in the middle branch between Station WC003 and Station WC002.

Total Annual Load

To facilitate comparison, samples collected in 2010 and 2011 were treated as fully "pre-restoration" and those collected in FY2017-2022 were treated as fully "post-restoration." If the ratio of pollutant load between the upstream station (WC003) and downstream station (WC002) during post-restoration conditions was less than the baseline ratio during pre-restoration conditions, then it may be concluded that the restoration projects reduced loading between the stations. Total loads and ratios are presented in Table 4-10. For comparison, intermediate post-restoration results using data collected in 2014, when no construction was in progress in the study area, are provided as in Jones et al. (2016).

In terms of total annual load, the ratios of the downstream station (WC002) to the upstream station (WC003) for total nitrogen and ammonia were greater during post-restoration conditions than during pre-restoration conditions. Lead, copper, zinc, BOD, total phosphorus, and TSS ratios were lower during the post-restoration phase, indicating that the restoration between the stations succeeded in reducing loads for these pollutants.

Storm EMCs

The ratios of average EMCs of pollutants during storm events captured during pre-restoration conditions were compared to the ratios of average EMCs for storms captured during post-restoration conditions. The average EMCs during these periods, and comparisons between periods, are provided in Table 4-11.

For all pollutants except ammonia, the average storm EMCs at the downstream station exceeded those at the upstream during pre-restoration; however, none of the differences were significant. After completion of restoration projects, the average storm EMCs of all pollutants at the downstream station were greater than at the upstream. Only the difference for total nitrogen was significant. The change in ratios suggests that the restoration in the contributing subwatersheds has reduced pollutant concentrations at Station WC002 under stormflow conditions for all parameters except for total nitrogen and ammonia.

Table 4-10. Comparison of Pre-Restoration and Post-Restoration Total Annual Loads

Phase	Total Load (lbs) WC002	Total Load (lbs) WC003	Ratio
Total Nitrogen			
Pre-Restoration (2010-2011)	7,258	1,905	73.8%
Post-Restoration (2014)	6,958	1,307	81.2%
Post-Restoration (FY 2017-22)	28,894.3	6,951.6	75.9%
Total Phosphorus			
Pre-Restoration (2010-2011)	281.8	73.9	73.8%
Post-Restoration (2014)	171.5	33.4	80.5%
Post-Restoration (FY 2017-22)	1,259.8	338.7	73.1%
TSS			
Pre-Restoration (2010-2011)	126,203	26,438	79.1%
Post-Restoration (2014)	67,237	12,413	81.5%
Post-Restoration (FY 2017-22)	308,360	109,289	64.6%
Ammonia			
Pre-Restoration (2010-2011)	72.4	32.1	55.7%
Post-Restoration (2014)	83.3	32.7	60.7%
Post-Restoration (FY 2017-22)	1,926.7	397.7	79.4%
BOD			
Pre-Restoration (2010-2011)	4,914	1,030	79.0%
Post-Restoration (2014)	14,168	2,918	79.4%
Post-Restoration (FY 2017-22)	47,754	14,033	70.6%
Copper			
Pre-Restoration (2010-2011)	19.2	4.9	74.3%
Post-Restoration (2014)	16.8	3.3	80.3%
Post-Restoration (FY 2017-22)	65.1	25.4	61.0%
Lead			
Pre-Restoration (2010-2011)	4.4	0.2	96.3%
Post-Restoration (2014)	3.3	0.5	84.1%
Post-Restoration (FY 2017-22)	11.1	4.0	64.1%
Zinc			
Pre-Restoration (2010-2011)	137.9	43.7	68.3%
Post-Restoration (2014)	101.1	24.2	76.1%
Post-Restoration (FY 2017-22)	405.2	146.8	63.8%

Table 4-11. Pre- and Post-Restoration Average Storm EMCs (shaded cells indicate significant results)				
Pollutant (mg/L)	Station		Ratio	t test p-value (two-tailed)
	WC002	WC003		
Pre-Restoration Conditions				
Total N	1.59	1.44	9%	0.54
Total P	0.104	0.073	30%	0.28
TSS	46.84	28.54	39%	0.20
Ammonia	0.017	0.030	-72%	0.50
BOD	2.400	1.585	34%	0.48
Copper	0.008	0.006	27%	0.36
Lead	0.479	0.000	100%	0.33
Zinc	0.043	0.038	11%	0.59
Post-Restoration Conditions				
Total N	1.59	1.35	15%	0.02
Total P	0.101	0.088	13%	0.45
TSS	33.96	28.41	16%	0.38
Ammonia	0.094	0.086	8%	0.72
BOD	4.791	3.646	24%	0.22
Copper	0.00711	0.00707	1%	0.96
Lead	0.0010	0.0008	20%	0.42
Zinc	0.0309	0.0307	1%	0.96
Note: For all pollutants, $\alpha = 0.05$				

Baseflow MCs

The ratios of average baseflow MCs of pollutants during pre-restoration conditions were compared to the ratios of average baseflow MCs during post-restoration conditions. The average MCs during these periods, and comparisons between periods, are provided in Table 4-12.

During pre-restoration phase baseflow conditions, total phosphorus, TSS, ammonia, copper, and zinc concentrations at the upstream station exceeded those at the downstream station, with TSS and zinc significant. Concentrations of BOD and total nitrogen were higher at the downstream station. After restoration, only BOD and zinc showed improvement in terms of lowering ratios between the upstream and downstream stations, with zinc showing a significant decrease. For the remaining parameters, concentrations at the downstream station became greater in relation to the upstream station, with total nitrogen and ammonia showing significant increases. The significantly higher ammonia concentrations at Station WC002 may be due to contributions of ammonia from a potential sanitary sewage source. Both EMCs and MCs for *E. coli* were highest at Station WC002, which contributes to evidence of potential sanitary sewage input.

Table 4-12. Pre- and Post-Restoration Average Baseflow MCs (shaded cells indicate significant results)

Pollutant (mg/L)	Station		Ratio	t test p-value (two-tailed)
	WC002	WC003		
Pre-Restoration Conditions				
Total N	2.14	1.88	12%	0.22
Total P	0.006	0.040	-617%	0.28
TSS	1.38	3.36	-144%	0.04
Ammonia	0.016	0.030	-86%	0.19
BOD	0.900	0.387	57%	0.25
Copper	0.001	0.002	-55%	0.23
Lead	0.0003	0.0003	0%	N/A
Zinc	0.017	0.021	-25%	0.01
Post-Restoration Conditions				
Total N	2.04	1.47	28%	<0.0001
Total P	0.034	0.012	66%	0.31
TSS	3.81	4.37	-15%	0.74
Ammonia	0.144	0.060	58%	<0.0001
BOD	1.460	1.508	-3%	0.96
Copper	0.0004	0.0004	-1%	0.97
Lead	0.0001	0.00004	74%	0.34
Zinc	0.015	0.022	-48%	<0.0001

Note: For all pollutants, $\alpha = 0.05$
N/A = not applicable

4.7.2 Subwatershed-level Evaluation of Pollutant Removal Efficiency

For this evaluation, average storm EMCs and baseflow MCs calculated during pre-restoration conditions were compared to those calculated during post-restoration conditions at each of the three monitoring stations to compute pollutant removal efficiency of upstream restoration projects. The pollutant removal efficiency is a straightforward method to determine the net overall benefit of restoration projects in the contributing subwatershed to each station.

Storm EMCs

The average storm EMCs of pollutants during storm events captured during pre-restoration conditions and post-restoration conditions at each station are provided in Table 4-13.

Table 4-13. Pre- and Post-Restoration Average Storm EMCs (shaded cells indicate significant results)				
Pollutant (mg/L)	**Phase**		**Percent Efficiency**	**t test p-value (two-tailed)**
	Pre-Restoration	**Post-Restoration**		
Station WC002				
Total N	1.59	1.56	2%	0.90
Total P	0.104	0.097	6%	0.81
TSS	46.84	31.54	33%	0.25
Ammonia	0.017	0.100	-483%	<0.0001
BOD	2.400	4.171	-74%	0.17
Copper	0.008	0.007	11%	0.63
Lead	0.479	0.001	100%	0.33
Zinc	0.043	0.032	27%	0.13
Station WC003				
Total N	1.44	1.30	10%	0.36
Total P	0.073	0.073	-0.1%	0.98
TSS	28.54	27.28	4%	0.88
Ammonia	0.030	0.094	-216%	0.01
BOD	1.585	3.151	-99%	0.06
Copper	0.006	0.007	-17%	0.59
Lead	0.000	0.001	N/A	<0.0001
Zinc	0.038	0.031	19%	0.28
Station WC004				
Total N	1.55	1.27	18%	0.03
Total P	0.068	0.063	7%	0.57
TSS	18.42	22.01	-20%	0.33
Ammonia	0.093	0.081	13%	0.58
BOD	2.536	3.360	-32%	0.17
Copper	0.007	0.007	-5%	0.67
Lead	0.001	0.001	-5%	0.85
Zinc	0.043	0.037	14%	0.19
Note: For all pollutants, $\alpha = 0.05$ N/A = not applicable				

At Station WC002, EMCs of all parameters except ammonia and BOD were reduced from pre-restoration conditions. The reduction in lead was effectively 100%. The reductions in total nitrogen, total phosphorus, TSS, copper, and zinc were lower, at 2%, 6%, 33%, 11%, and 27%, respectively. Ammonia and BOD increased by 483% and 74% respectively, with the increase in ammonia being significant.

At Station WC003, stormflow total nitrogen, TSS, and zinc decreased between pre-restoration and post-restoration conditions by 10%, 4%, and 19%, respectively. Ammonia, BOD, copper, and lead increased between pre- and post-restoration phases, with ammonia and lead significant. Total phosphorus increased slightly by 0.1%.

At Station WC004, total nitrogen, total phosphorus, ammonia, and zinc decreased between pre-restoration and post-restoration conditions, by 18%, 7%, 13%, and 14%, respectively, with nitrogen significant. TSS, BOD, copper, and lead increased by between 5% and 32% after completion of restoration activities.

Baseflow MCs

The average baseflow MCs of pollutants during pre-restoration conditions and post-restoration conditions at each station are provided in Table 4-14.

At Station WC002 baseflow MCs for total nitrogen, copper, lead, and zinc were reduced after completion of restoration projects in the contributing subwatershed by between 4% and 88%. The remaining parameters increased between pre-restoration and post-restoration by 17% for BOD, 187% for TSS, over seven times for total phosphorus, and nearly 11 times for ammonia, with both TSS and ammonia showing significant increases.

At Station WC003, baseflow data show the restoration projects in the contributing subwatershed reduced pollutants by efficiencies ranging from 0.3% for zinc to 87% for lead. BOD dramatically increased by over four-fold, though not significantly. Ammonia increased by 122%.

At Station WC004, baseflow concentrations for six of eight parameters declined between pre-restoration and post-restoration conditions, with significant reductions for copper and zinc. Only TSS (251%) and BOD (71%) were greater during post-restoration than pre-restoration.

4.8 LONG-TERM TREND ANALYSIS OF WATER CHEMISTRY DATA

The time-series statistical tests performed on baseflow concentration and individual storm EMC data collected showed significant, downward trends for both baseflow and storm flow nitrate plus nitrite at all stations, plus baseflow zinc at all stations and stormflow zinc at Station WC002 and Station WC003. Constituents that significantly increased over time were the following: baseflow TSS at Stations WC002 and WC004, baseflow ammonia at all stations, stormflow ammonia at Stations WC002 and WC003, baseflow TKN at all stations, stormflow TKN at Stations WC003 and WC004, baseflow lead at all stations, and baseflow total phosphorus at all stations. Overall, the results were mixed, with 26 of the 54 EMCs and MCs examined under all flow conditions at all stations becoming lower over time. A summary of test results, including coefficients and significance, for indicator parameters is presented in Table 4-15.

The reduction at all stations and flow types, much of it significant, for nitrate plus nitrite, copper, and zinc over time, occurred despite the reduction in detection limits by the analytical laboratory. A reduction in detection limits would potentially cause upward-trending data due to less non-detectible results, which are treated as zero in the data analysis in this report. Downward trending metals concentrations during baseflow conditions were in opposition to upward trending TSS concentrations during baseflow, which may be due to effects of changes in detection limits for some samples. A closer examination of detection limit effects may be presented in a future report.

Table 4-14. Pre- and Post-Restoration Average Baseflow MCs (shaded cells indicate significant results)

Pollutant (mg/L)	Phase: Pre-Restoration	Phase: Post-Restoration	Percent Efficiency	t test p-value (two-tailed)
Station WC002				
Total N	2.14	2.04	4%	0.53
Total P	0.006	0.041	-621%	0.20
TSS	1.38	3.97	-187%	0.03
Ammonia	0.016	0.172	-981%	<0.0001
BOD	0.900	1.050	-17%	0.79
Copper	0.001	0.0005	52%	0.21
Lead	0.0003	0.00004	88%	0.39
Zinc	0.017	0.014	14%	0.49
Station WC003				
Total N	1.88	1.45	23%	0.07
Total P	0.040	0.012	70%	0.38
TSS	3.36	2.94	12%	0.69
Ammonia	0.030	0.066	-122%	0.14
BOD	0.387	1.677	-333%	0.29
Copper	0.002	0.0005	69%	0.09
Lead	0.0003	0.00005	87%	0.39
Zinc	0.021	0.021	0%	0.99
Station WC004				
Total N	3.49	3.25	7%	0.25
Total P	0.017	0.011	37%	0.49
TSS	0.66	2.31	-251%	0.08
Ammonia	0.052	0.020	61%	0.12
BOD	0.353	0.602	-71%	0.48
Copper	0.002	0.0006	68%	0.0005
Lead	0.0002	0.00009	48%	0.38
Zinc	0.037	0.022	41%	0.004

Note: For all pollutants, $\alpha = 0.05$
N/A = not applicable

Table 4-15. Results of Kendall's Tau-b significance tests for indicator parameters (2010-FY2022)

Parameter	WC002		WC003		WC004	
	Storm	Baseflow	Storm	Baseflow	Storm	Baseflow
Nitrate + Nitrite	0.0032 (-)	< 0.0001 (-)	< 0.0001 (-)	< 0.0001 (-)	< 0.0001 (-)	0.0064 (-)
Total Kjeldahl Nitrogen	N.S.	< 0.0001 (+)	0.0095 (+)	< 0.0001 (+)	0.0156 (+)	< 0.0001 (+)
Total Phosphorus	N.S.	< 0.0001 (+)	N.S.	0.0019 (+)	N.S.	0.0048 (+)
TSS	N.S.	< 0.0001 (+)	N.S.	N.S.	N.S.	0.0034 (+)
Ammonia	< 0.0001 (+)	< 0.0001 (+)	0.0023 (+)	< 0.0001 (+)	N.S.	0.0163 (+)
BOD	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Copper	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
Lead	N.S.	0.0104 (+)	N.S.	0.0286 (+)	N.S.	0.0088 (+)
Zinc	0.0022 (-)	0.0024 (-)	0.0275 (-)	0.0197 (-)	N.S.	0.0099 (-)

Positive (+) symbols or orange shading indicate an increasing trend over time; negative (-) symbols or green shading indicate a decreasing trend over time; no shading indicates no trend
N.S. = not significant

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5.0 CONCLUSIONS

In a cooperative effort, Harford County DPW, Versar, and USGS conducted water chemistry and long-term flow monitoring in the Wheel Creek watershed from July 1, 2021 through June 30, 2022. The monitoring effort included twelve baseflow sampling and eight wet weather sampling events with suspended sediment transport sampling. The final wet weather event of FY2021 initiated on June 30, 2021, counting towards the permit requirements for Harford County, but continued until July 2, 2021; therefore, discharge and chemical results for this storm fall within this permit year and are included in this assessment. Baseflow and stormflow monitoring consisted of sampling for suspended solids, copper, lead, zinc, BOD, ammonia, nitrate plus nitrite, chloride, orthophosphate, total phosphorous, TKN, turbidity, hardness, TPH, and *E. coli*.

5.1 SUMMARY OF MONITORING RESULTS

Federal and State reference values for certain nutrients were exceeded on several occasions, confirming detrimental stream chemistry impacts from development and changes in land use. Total nitrogen, calculated from the sum of nitrate plus nitrite and TKN, was present at concentrations exceeding the EPA reference values (0.69 mg/L) for both baseflow (all detected samples) and stormflow (97.5% of samples). For total phosphorus, 69.4% of the detectible results in baseflow samples and 74.3% of the detectible results in stormflow samples were found to be above the corresponding EPA reference concentration (0.03656 mg/L). Only one reported chloride concentration in stormflow samples exceeded the EPA acute criterion (860 mg/L), while 27.8% of baseflow samples exceeded the chronic criterion for chloride (230 mg/L).

All baseflow samples had detectable amounts of zinc but none exceeded the MDE chronic surface water criterion (120 µg/L). Of the stormflow samples, 98.8% had detectable concentrations of zinc, but none exceeded the MDE acute criterion (120 µg/L). All lead concentrations fell below the MDE acute criterion (65 µg/L) for stormflow and the chronic criterion (2.5 µg/L) for baseflow this monitoring period. Copper concentrations did not exceed the MDE chronic criterion (9 µg/L) in baseflow samples, while 2.5% of stormflow samples exceeded the acute criterion (13 µg/L).

E. coli bacteria concentrations were detected in all baseflow samples at all stations, ranging in concentration from 9.6 to >2,420 MPN/100ml. *E. coli* concentrations were equal to or greater than the maximum reportable result in 18.5% of stormflow grab samples, down from 28.6% in the FY2021 monitoring period. TPH was not detected above the reporting limit in any of the stormflow or baseflow grab samples collected at the monitoring.

Average baseflow concentrations of combined nitrate plus nitrite, TKN, total phosphorus, chloride, copper, lead, and zinc were highest at Station WC004 compared to the other two stations downstream. Samples collected at Station WC003 had the highest average concentrations of TSS during baseflow conditions. Station WC002 samples had the highest average concentrations of BOD, ammonia, orthophosphate, and *E. coli* at baseflow. Average stormflow EMCs were highest at Station WC004 for BOD, ammonia, TKN, and zinc. Average EMCs for combined nitrate plus nitrite, orthophosphate, total P, TSS, copper, lead, and *E. coli* were highest at Station WC002. At

Station WC003, the EMC for chloride was highest of the three stations. Average EMCs of all pollutants at all stations were lower than Maryland and national average values.

Average stormflow loads were highest at Station WC002 and lowest at Station WC004 for all parameters. Since discharge volume for a given storm increases with distance downstream, maximum load results at Station WC002 are expected.

Suspended sediment transport showed a low correlation with discharge at Station WC002 ($r^2 = 0.355$), a moderate correlation at Station WC003 ($r^2 = 0.772$), and a high correlation at Station WC004 ($r^2 = 0.998$); suspended sediment concentrations per discharge were only recorded in three samples at Station WC004 in FY2022 so this correlation is the result of an extremely small sample size and likely not a significant relationship.

5.2 SUMMARY OF RESTORATION EFFECTIVENESS

Comparisons of pre-restoration and post-restoration pollutant load and concentration data were performed to determine the benefit to watershed conditions as a result of the implementation of the several restoration projects. Restoration activity initiated in late summer 2012 and concluded in spring 2017, allowing a post-restoration collection of data to be accumulated. Subwatershed-level and total watershed benefits were evaluated by comparing concentration and loading data from specific stations during applicable pre-restoration and post-restoration timelines for projects within the catchments of those stations.

Comparing ratios of average concentrations and loads at Stations WC003 and WC002, determined first under pre-restoration conditions and then under post-restoration conditions, produced mixed results. Comparisons of load ratios identified total phosphorus, TSS, BOD, copper, lead, and zinc as being reduced by restoration. Concentration ratio results suggest that the restoration in the contributing subwatersheds has reduced total phosphorus, TSS, BOD, copper, lead, and zinc in the contributing drainage between Stations WC002 and WC003 under stormflow conditions. Under baseflow concentrations, only BOD and zinc showed improvement in terms of lowering percentage differences between the upstream and downstream stations.

Directly comparing post-restoration concentrations (both storm and baseflow) to pre-restoration concentrations showed the following: At Station WC002, storm EMCs of total nitrogen, total phosphorus, TSS, copper, lead, and zinc were reduced from pre-restoration conditions. At Station WC003, stormflow total nitrogen, TSS, and zinc decreased between pre-restoration and post-restoration conditions. At Station WC004, total nitrogen, total phosphorus, ammonia, and zinc decreased between pre-restoration and post-restoration conditions. At Station WC002, baseflow total nitrogen, copper, lead, and zinc MCs were reduced after completion of restoration projects in the contributing subwatershed. At Station WC003, baseflow concentration data show the restoration projects in the contributing subwatershed reduced total nitrogen, total phosphorus, TSS, copper, lead, and zinc. At Station WC004, baseflow efficiency results showed that total nitrogen, total phosphorus, ammonia, copper, lead, and zinc were reduced between pre-restoration conditions and post-restoration. A summary of the results of tests of restoration effectiveness is provided in Table 5-1.

Table 5-1. Results of tests of restoration effectiveness (bullets indicate pollutant reduction between post- and pre-restoration conditions)

	Target Sub-watershed	Parameter							
		BOD	Ammonia	Total P	TSS	Total N	Copper	Lead	Zinc
Ratio Loads	WC002 below WC003	•		•	•		•	•	•
Ratio EMC	WC002 below WC003	•		•	•		•	•	•
Ratio MC	WC002 below WC003	•							•
Before After EMC	WC002			•	•	•	•	•	•
Before After EMC	WC003				•	•			•
Before After EMC	WC004		•	•		•			•
Before After MC	WC002					•	•	•	•
Before After MC	WC003			•	•	•	•	•	•
Before After MC	WC004		•	•		•	•	•	•

The time-series statistical test performed on baseflow concentration and individual storm EMC data collected showed significant, downward trends for both baseflow and storm flow nitrate plus nitrite at all stations, plus baseflow zinc at all stations and stormflow zinc at Station WC002 and Station WC003. Constituents that significantly increased over time were the following: baseflow TSS at Stations WC002 and WC004, baseflow ammonia at all stations, stormflow ammonia at Stations WC002 and WC003, baseflow TKN at all stations, stormflow TKN at Stations WC003 and WC004, baseflow lead at all stations, and baseflow total phosphorus at all stations. Overall, the results were mixed, with 26 of the 54 EMCs and MCs examined under all flow conditions at all stations becoming lower over time. The number of both downward-trending EMCs and MCs and significantly downward-trending EMCs and MCs increased compared to FY2021. The number of significantly upward-trending EMCs and MCs also increased, which indicates that current-year post-restoration data continue to reinforce trends in previously collected data.

Time series plots of annual average EMCs and MCs for most parameters show continuing stabilization or apparent, downward short-term trends in TSS, copper, lead, zinc, BOD and nitrate plus nitrite during the period after FY2017 and FY2018 to present. The timing of the above short-term concentration trends may indicate a cause-and-effect relationship with the completion of restoration projects in the watershed. Exceptions to the above short-term trends include ammonia and TKN, which during the past three monitoring years have been generally trending higher, more noticeably for baseflow MCs. As ammonia is a component of TKN, an increase in ammonia would likely cause a corresponding increase in TKN. Total phosphorus shows inter-annual variability but with no discernible trend. Baseflow ammonia at Station WC002 continued its dramatically upward trend, which began in FY2017. The cause may be a potentially significant input from an unusual source, such as a sanitary sewer line between Stations WC002 and WC003 or within commercial and residential areas around the mainstem upstream of Station WC002. Baseflow concentrations of TKN at all stations have been gradually increasing since well-before the completion of construction and may be driven by gradual increases in organic nitrogen in the watershed.

Results of comparisons of post-restoration to pre-restoration concentrations show that effectiveness was roughly evenly distributed amongst the three stations, and mostly reflected in baseflow conditions (Table 5-1). When comparing ratios of concentrations at Stations WC002 and WC003 to isolate restoration work in contributing watersheds between the two stations, concentrations in storm runoff have been reduced for eight of 16 parameters. The results of analysis of ratios of loads show benefits in six of eight parameters. As monitoring has continued, the number of parameters that show pollutant reductions amongst the restoration effectiveness tests described above has gradually increased since the first full year of post-restoration monitoring (FY2018), especially for total phosphorus, TSS, and zinc. Note that zinc showed reductions for all tests. An analysis of the effects of the change in analytical laboratory during FY2019 on the determination of restoration effectiveness has not been conducted, but may appear in a subsequent report.

6.0 REFERENCES

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APPENDIX A

STORM EVENT SUMMARY REPORTS

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WHEEL CREEK STORM MONITORING SUMMARY REPORT

JUNE 30 – JULY 2, 2021

INTRODUCTION

Versar field staff traveled to the site on June 30 to program the SIGMA automated samplers to sample the event. Rainfall initiated at approximately 19:32 p.m. the evening of Wednesday, June 30. At the Wheel Creek Rain Gauge Station, 1.07 inches of rain was recorded for the duration of the storm.

On the morning of July 2, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the falling limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on July 2 to composite automated samples. Composite samples, including TPH, were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on July 2 for analysis. Siphon samples were delivered to Enviro-Chem Laboratories for analysis of SSC on July 2, 2021.

The following problems occurred during the storm event:

The storm flow elevation continued beyond the anticipated program therefore the field crew took falling grabs at all three sites during their respective composite times.

RESULTS

Hydrographs for the June 30 – July 2 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the June 30 – July 2 event are shown in Table A-5.

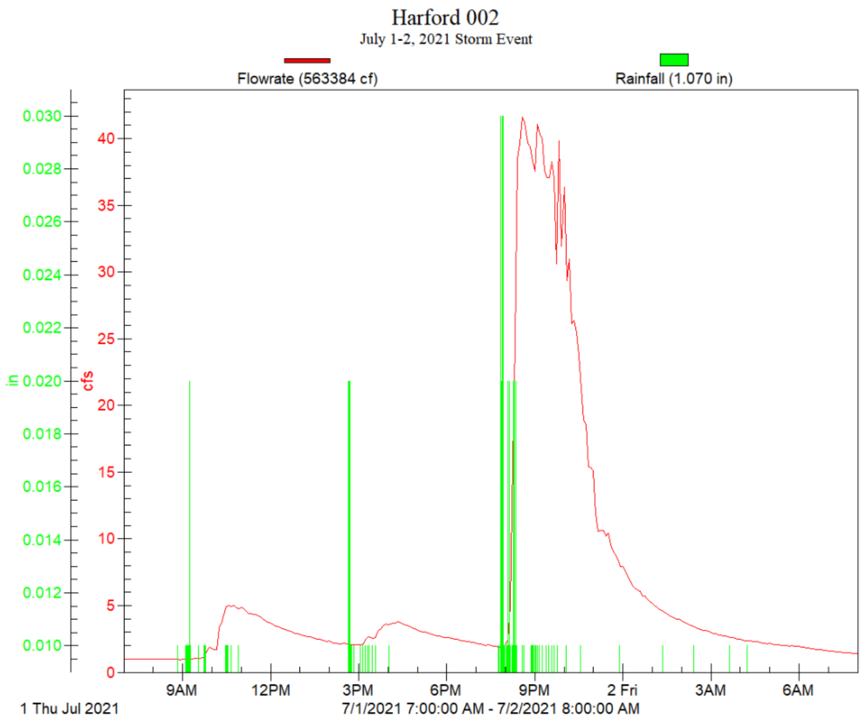

Figure A-1. Hydrograph at Station WC002 for July 1-2, 2021 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

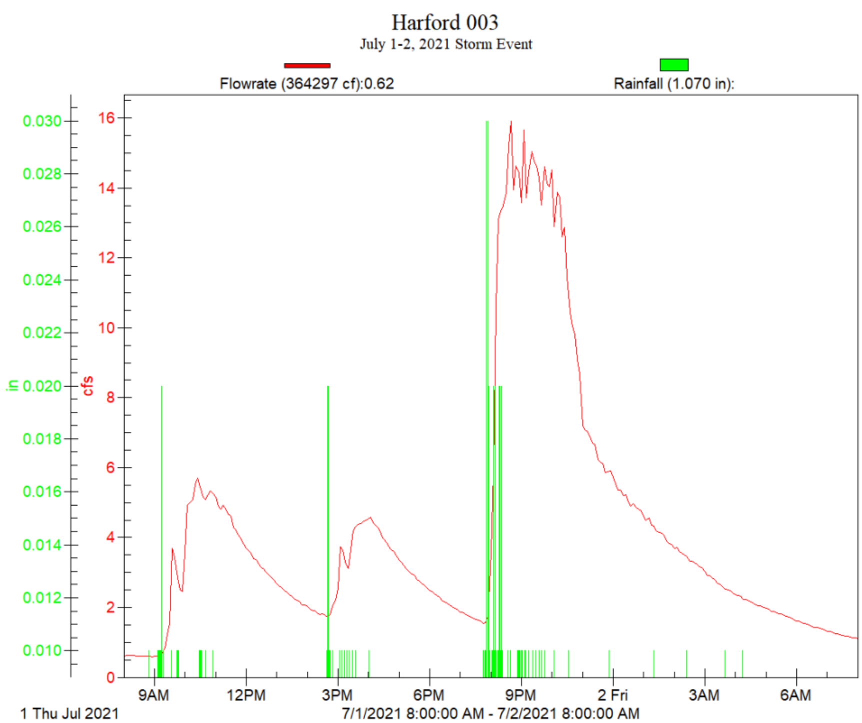

Figure A-2. Hydrograph at Station WC003 for July 1-2, 2021 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

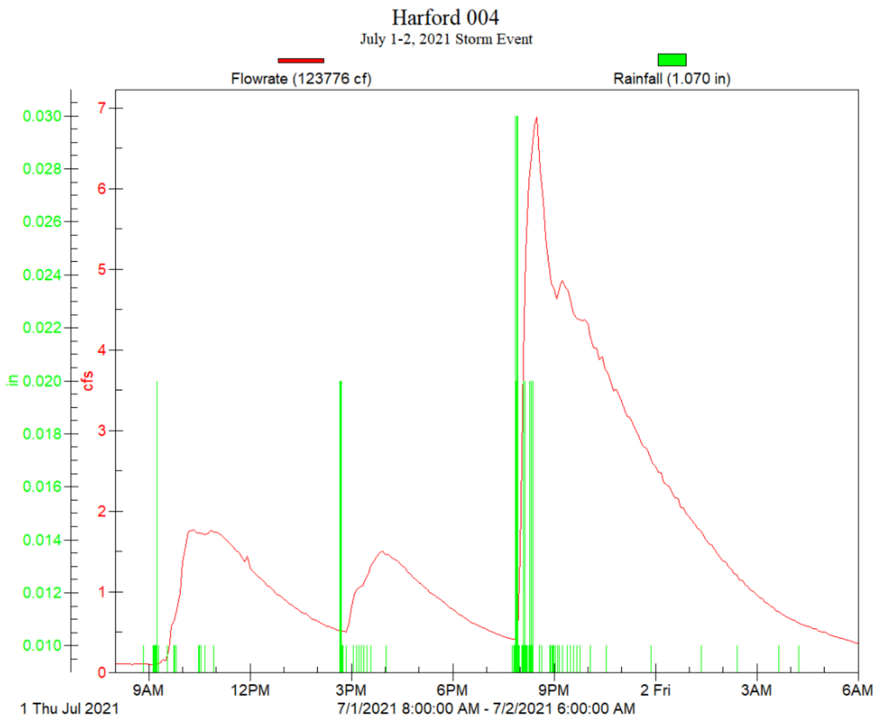

Figure A-3. Hydrograph at Station WC004 for July 1-2, 2021 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb

Constituent	30 June-2 July, 2021		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	3.6	6.1	3.1
Nitrate-Nitrite Nitrogen	0.75	0.45	0.62
Orthophosphate Phosphorus	<0.02	<0.02	<0.02
Solids (Suspended)	<4	6	<4
Copper	0.007	0.006	0.007
Lead	0.0006	0.0007	0.001
Zinc	0.013	0.016	0.036
Ammonia Nitrogen	<0.1	0.27	<0.1
Kjeldahl Nitrogen (Total)	0.86	1.72	2.04
Total Phosphorus	0.13	0.17	0.11
Hardness	74	95	86
Chloride	60.6	66.1	97.2
pH	7.43	7.19	7

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb

Constituent	30 June-2 July, 2021		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	<2	2.6	2.1
Nitrate-Nitrite Nitrogen	1.52	0.41	0.19
Orthophosphate Phosphorus	0.04	0.02	<0.02
Solids (Suspended)	<4	6.8	<4
Copper	0.003	0.007	0.005
Lead	0.0001	0.0009	0.0005
Zinc	0.006	0.016	0.015
Ammonia Nitrogen	<0.1	<0.1	<0.1
Kjeldahl Nitrogen (Total)	0.64	0.96	0.83
Total Phosphorus	<0.1	<0.1	<0.1
Hardness	144	54	26
Chloride	84.4	58.5	<50
pH	7.27	7.34	7.1

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb

Constituent	30 June-2 July, 2021		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	<2	<2	<2
Nitrate-Nitrite Nitrogen	0.79	0.66	0.36
Orthophosphate Phosphorus	0.03	0.02	0.02
Solids (Suspended)	<4	<4	<4
Copper	0.002	0.002	0.002
Lead	0.0003	0.0003	0.0004
Zinc	0.009	0.007	0.011
Ammonia Nitrogen	<0.1	<0.1	<0.1
Kjeldahl Nitrogen (Total)	0.87	1.22	0.76
Total Phosphorus	<0.1	<0.1	<0.1
Hardness	84	88	50
Chloride	69.7	88.7	39.8
pH	7.4	7.28	7.15

Table A-4. Analytical Results – Wheel Creek Grab Sampling			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
July 2, 2021 (Falling)			
TPH (mg/L)	<5	<5	<5
E. coli (MPN/100 ml)	1410	1550	>2420
Temp (C)	22.3	21.8	22.6
DO (mg/L)	8.27	7.82	6.67
pH	7.40	7.03	7.16
Sp. Cond. (mS/cm)	0.333	0.338	0.227

Table A-5. Rainfall and flow statistics			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
Rainfall (in.)	1.07	1.07	1.07
Duration (hrs.)	24	24	22
Intensity (in./hr.)	0.045	0.045	0.049
Discharge (cf.)	563,384	364,297	123,776

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WHEEL CREEK STORM MONITORING SUMMARY REPORT

AUGUST 16-17, 2021

INTRODUCTION

Versar field staff traveled to the site on August 16 to deploy siphon samplers and program the SIGMA automated samplers to sample the event. Rainfall initiated at approximately 20:24 p.m. the evening of Monday, August 16. At the Wheel Creek Rain Gauge Station, 0.18 inches of rain was recorded for the duration of the storm.

On the morning of August 18, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the falling limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on August 18 to composite automated and suspended sediment concentration samples (SSC). Siphon samples were submitted to the laboratory for analysis of SSC on August 18. Composite samples, including TPH, were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on August 18.

RESULTS

Hydrographs for the August 16-17 storm are presented in Figures A-1 through A-3 below. Precipitation during this event resulted in two peaks in stream discharge. Compositing was done according to discharge volume per limb; rising and falling limbs were picked from portions of the storm that best represent those conditions, subject to availability of discrete samples. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the August 16-17 event are shown in Table A-5.

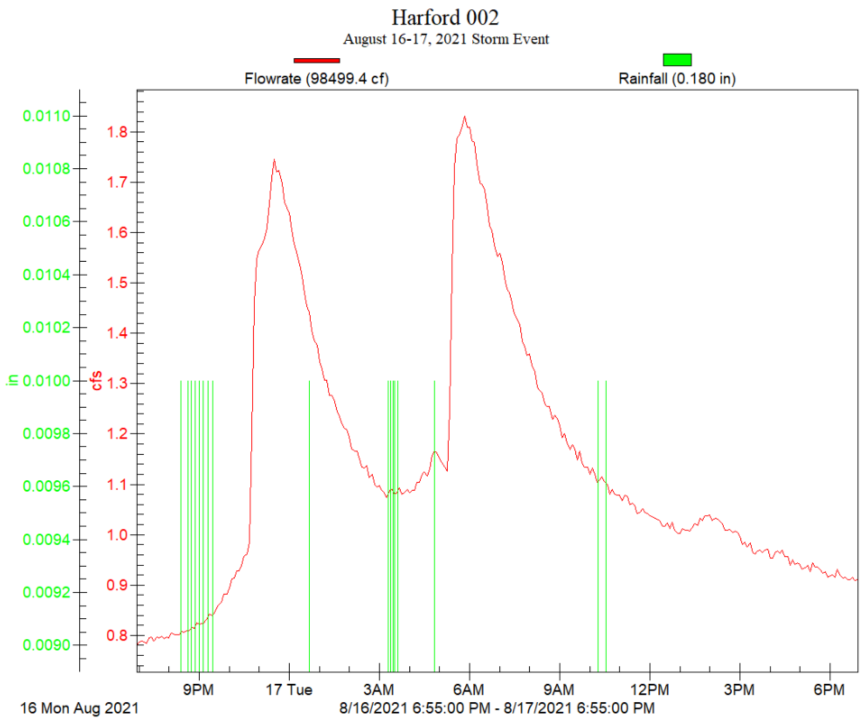

Figure A-1. Hydrograph at Station WC002 for August 16-17, 2021 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

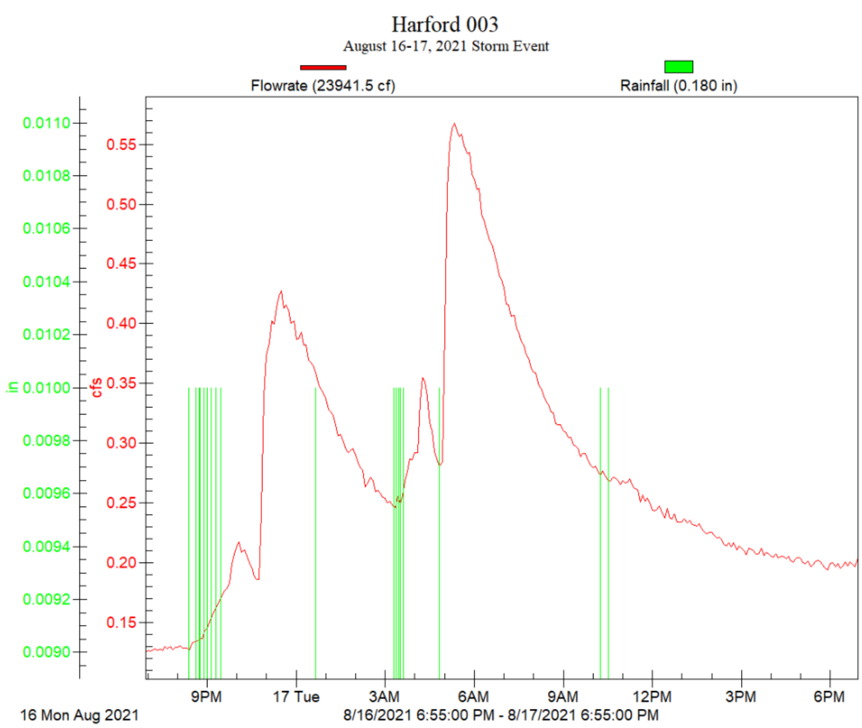

Figure A-2. Hydrograph at Station WC003 for August 16-17 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

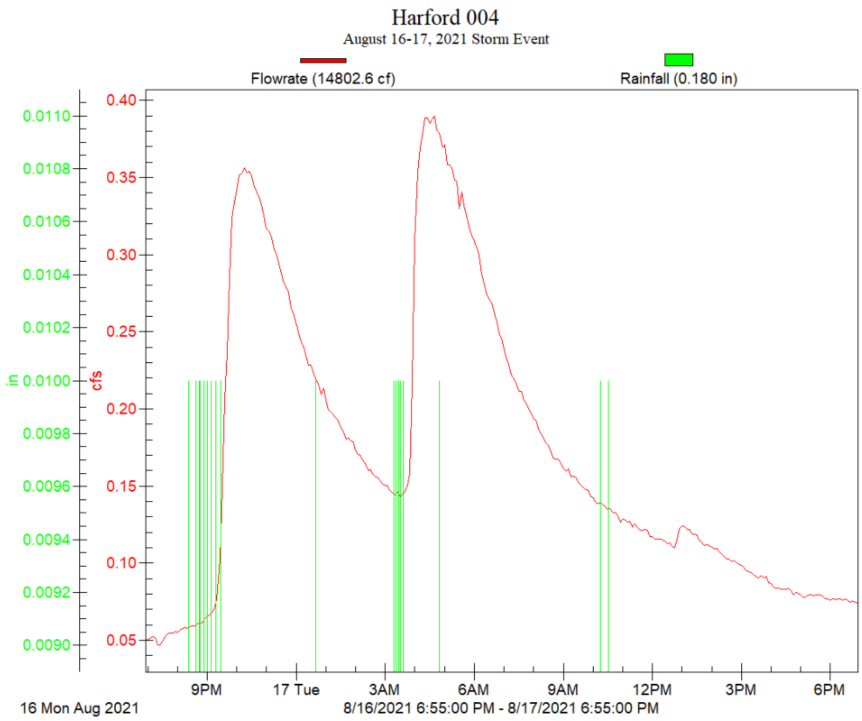

Figure A-3. Hydrograph at Station WC004 for August 16-17 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb			
Constituent	16-17 August, 2021		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	3	3	34
Nitrate-Nitrite Nitrogen	0.9	0.7	<0.2
Orthophosphate Phosphorus	0.06	<0.05	<0.05
Solids (Suspended)	76	14	28
Copper	0.015	0.004	0.009
Lead	0.004	0.0001	0.0009
Zinc	0.02	0.009	0.024
Ammonia Nitrogen	0.29	0.23	<0.3
Kjeldahl Nitrogen (Total)	1.3	3.3	0.9
Total Phosphorus	0.23	0.27	0.09
Hardness	150	166	122
Chloride	105	123	102
pH	7.31	7.06	7.23

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb

Constituent	16-17 August, 2021		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	2	1	2
Nitrate-Nitrite Nitrogen	0.6	0.4	0.1
Orthophosphate Phosphorus	0.01	<0.05	<0.05
Solids (Suspended)	4	5	11
Copper	0.003	0.003	0.011
Lead	<0.001	0.0002	0.002
Zinc	<0.01	0.006	0.024
Ammonia Nitrogen	0.06	0.07	0.07
Kjeldahl Nitrogen (Total)	0.7	0.7	0.8
Total Phosphorus	0.05	0.04	0.05
Hardness	116	130	92
Chloride	88.7	108	69.8
pH	7.4	7.36	7.07

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb

Constituent	16-17 August, 2021		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	1	<1	1
Nitrate-Nitrite Nitrogen	0.7	0.5	0.7
Orthophosphate Phosphorus	<0.05	<0.05	<0.05
Solids (Suspended)	6	3	<2
Copper	0.003	0.003	0.003
Lead	<0.001	<0.001	0.0001
Zinc	0.003	0.006	0.01
Ammonia Nitrogen	0.07	0.09	0.12
Kjeldahl Nitrogen (Total)	0.7	0.4	0.9
Total Phosphorus	0.04	0.03	0.02
Hardness	143	140	138
Chloride	106	110	125
pH	7.49	7.56	7.19

Table A-4. Analytical Results – Wheel Creek Grab Sampling			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
August 16-17, 2021 (Falling)			
TPH (mg/L)	<5	<5	<5
E. coli (MPN/100 ml)	816	488	261
Temp (C)	23.2	23.9	23.6
DO (mg/L)	8.18	8.11	6.24
pH	7.21	7.23	7.02
Sp. Cond. (mS/cm)	0.453	0.492	0.629

Table A-5. Rainfall and flow statistics			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
Rainfall (in.)	0.18	0.18	0.18
Duration (hrs.)	24	24	24
Intensity (in./hr.)	0.008	0.008	0.008
Discharge (cf.)	98,499	23,942	14,803

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WHEEL CREEK STORM MONITORING SUMMARY REPORT

SEPTEMBER 1-2, 2021

INTRODUCTION

Versar field staff traveled to the site on August 31 to deploy siphon samplers and program the SIGMA automated samplers to sample the event. Rainfall initiated at approximately 01:29 a.m. the morning of Wednesday, September 1. At the Wheel Creek Rain Gauge Station, 4.30 inches of rain was recorded for the duration of the storm.

On the morning of September 2, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the peak limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on September 3, to composite automated and suspended sediment concentration samples (SSC). Siphon samples were submitted to the laboratory for analysis of SSC on September 13. Composite samples, including TPH samples were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on September 3.

The following problems occurred during the storm event:

This event was sampled during the Hurricane Ida storm event. The ISCO bubbler tubing detached at stations WC002 and WC003 after bottle 13, a falling grab was obtained during the morning of 9/2/21 for all 3 stations. Both small sampler batteries died as well during the rain event at WC002 and WC003. Versar field crew noticed that a large tree fell at the WC004 station during the storm event. No County instrumentation was damaged during the tree fall but could experience an issue in the future with debris and erosion in and around the stream.

RESULTS

Hydrographs for the September 1-2 storm are presented in Figures A-1 through A-3 below. Precipitation during this event resulted in two peaks in stream discharge. Compositing was done according to discharge volume per limb; rising and falling limbs were picked from portions of the storm that best represent those conditions, subject to availability of discrete samples. Laboratory analytical and field water quality results for the September 1-2 storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the event are shown in Table A-5.

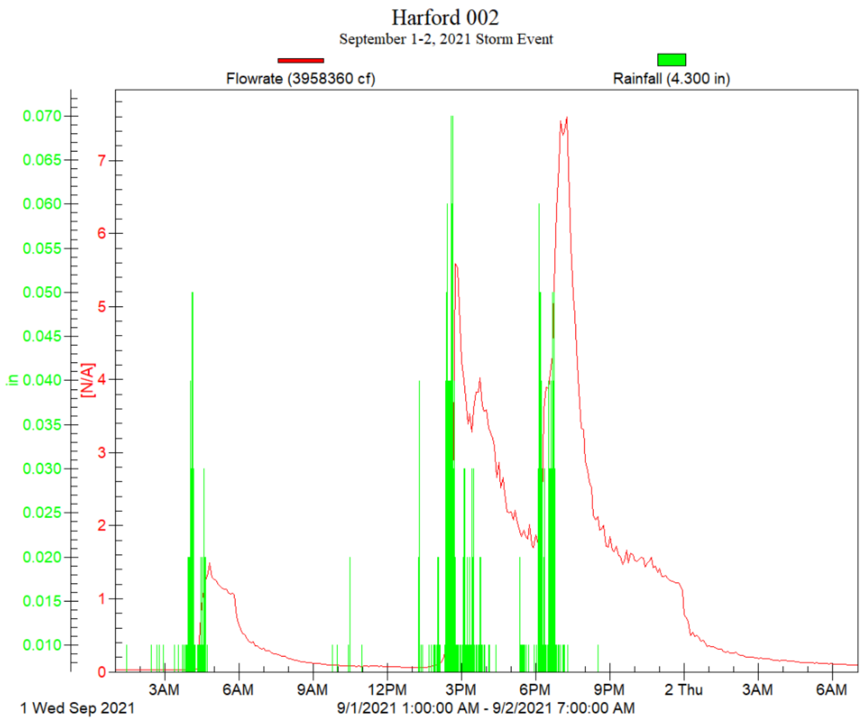

Figure A-1. Hydrograph at Station WC002 for September 1-2, 2021 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

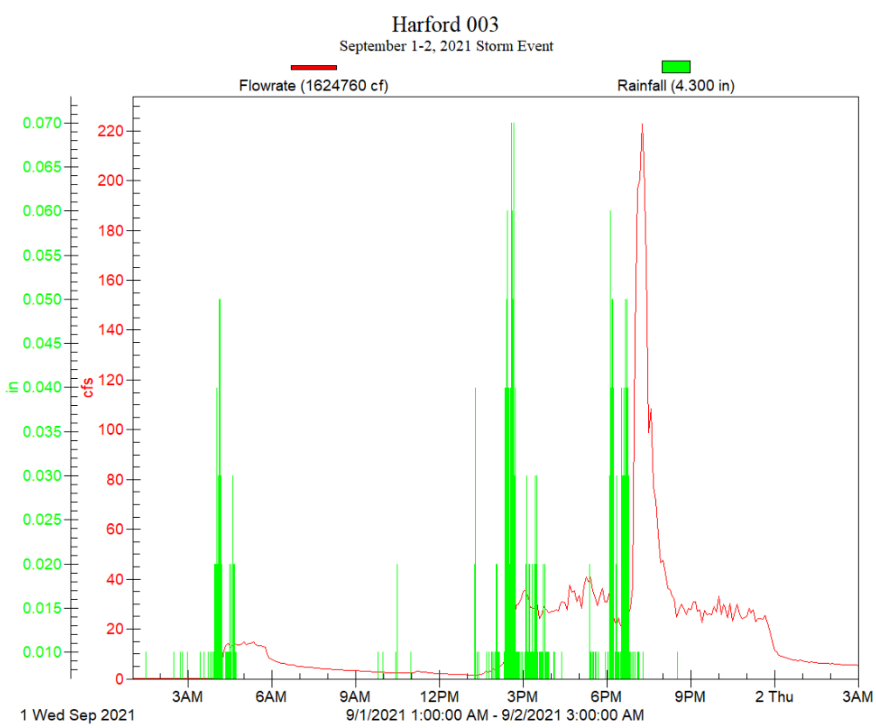

Figure A-2. Hydrograph at Station WC003 for September 1-2, 2021 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

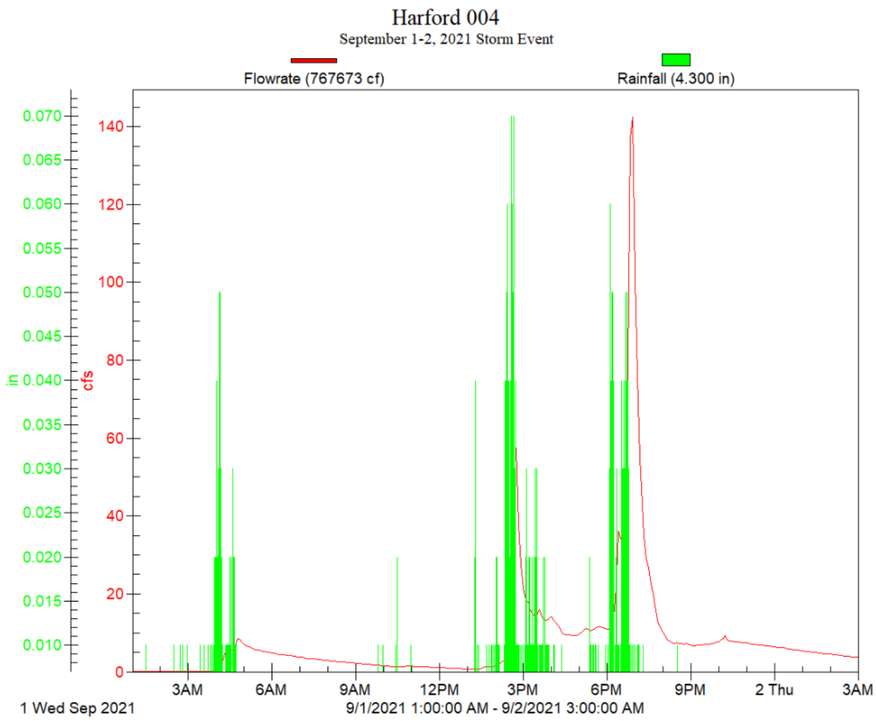

Figure A-3. Hydrograph at Station WC004 for September 1-2, 2021 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb

Constituent	1-2 September, 2021		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	2	2	1
Nitrate-Nitrite Nitrogen	0.4	0.3	0.2
Orthophosphate Phosphorus	0.02	0.07	0.02
Solids (Suspended)	6	11	8
Copper	0.006	0.005	0.005
Lead	0.0008	0.0007	0.0006
Zinc	0.019	0.014	0.017
Ammonia Nitrogen	0.11	<0.3	<0.3
Kjeldahl Nitrogen (Total)	0.7	0.7	0.6
Total Phosphorus	0.09	0.07	0.05
Hardness	42	56	40
Chloride	35.9	<25	32.4
pH	7.09	7.36	7.08

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb			
Constituent	1-2 September, 2021		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	3	2	1
Nitrate-Nitrite Nitrogen	0.4	0.3	0.1
Orthophosphate Phosphorus	0.05	0.05	0.09
Solids (Suspended)	63	32	9
Copper	0.015	0.002	0.005
Lead	0.003	0.0002	0.0007
Zinc	0.042	0.008	0.014
Ammonia Nitrogen	0.05	0.07	<0.3
Kjeldahl Nitrogen (Total)	1.2	1	0.5
Total Phosphorus	0.23	0.11	0.05
Hardness	16	48	18
Chloride	26.9	43.8	<25
pH	7.04	7.26	7.08

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb			
Constituent	1-2 September, 2021		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	<1	<1	<1
Nitrate-Nitrite Nitrogen	0.5	0.3	0.3
Orthophosphate Phosphorus	0.02	<0.05	0.01
Solids (Suspended)	<2	2	4
Copper	0.003	0.01	0.002
Lead	0.0002	0.001	0.0004
Zinc	0.01	0.025	0.012
Ammonia Nitrogen	<0.3	<0.3	<0.3
Kjeldahl Nitrogen (Total)	0.5	0.4	0.3
Total Phosphorus	0.07	0.03	0.03
Hardness	54	32	28
Chloride	<25	35.6	30.6
pH	7.2	7.15	6.94

Table A-4. Analytical Results – Wheel Creek Grab Sampling			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
September 2, 2021 (Peak)			
TPH (mg/L)	<5	<5	<5
E. coli (MPN/100 ml)	>2420	1410	727
Temp (C)	21.2	21.6	21.5
DO (mg/L)	8.50	8.45	7.65
pH	7.13	7.22	6.88
Sp. Cond. (mS/cm)	0.188	0.167	0.134

Table A-5. Rainfall and flow statistics			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
Rainfall (in.)	4.3	4.3	4.3
Duration (hrs.)	30	26	26
Intensity (in./hr.)	0.143	0.165	0.165
Discharge (cf.)	3,958,360	1,624,760	767,673

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WHEEL CREEK STORM MONITORING SUMMARY REPORT

DECEMBER 11-12, 2021

INTRODUCTION

Versar field staff traveled to the site on December 11 to deploy siphon samplers and program the SIGMA automated samplers to sample the event. Rainfall initiated at approximately 19:56 p.m. the morning of Saturday, December 11. At the Wheel Creek Rain Gauge Station, 0.14 inches of rain was recorded for the duration of the storm.

On the afternoon of December 13, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the falling limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on December 13 to composite automated and suspended sediment concentration samples (SSC). Siphon samples were submitted to the laboratory for analysis of SSC on December 16. Composite samples were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on December 13.

RESULTS

Hydrographs for the December 11-12 storm are presented in Figures A-1 through A-3 below. This was a minimal precipitation event, and there was a lot of noise in the flow rate data at this time, resulting in poor hydrographs at Stations WC002 and WC003. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the December 11-12 event are shown in Table A-5.

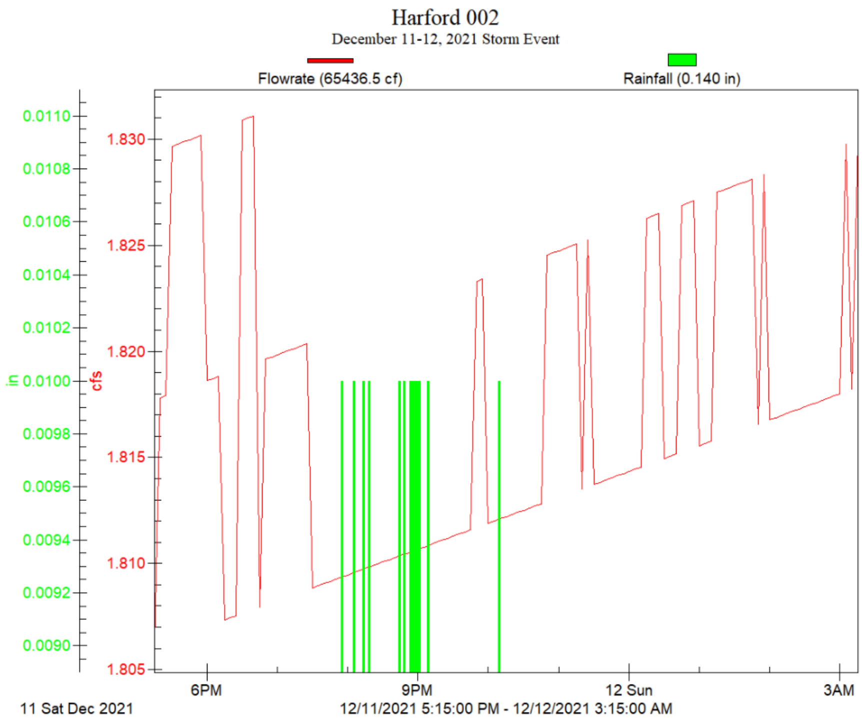

Figure A-1. Hydrograph at Station WC002 for December 11-12, 2021 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

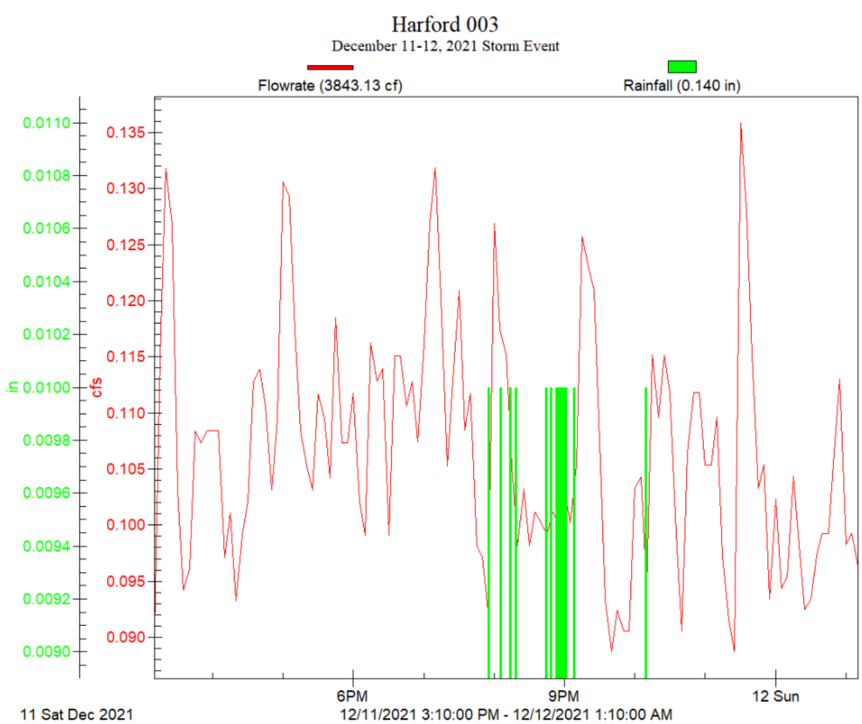

Figure A-2. Hydrograph at Station WC003 for December 11-12, 2021 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

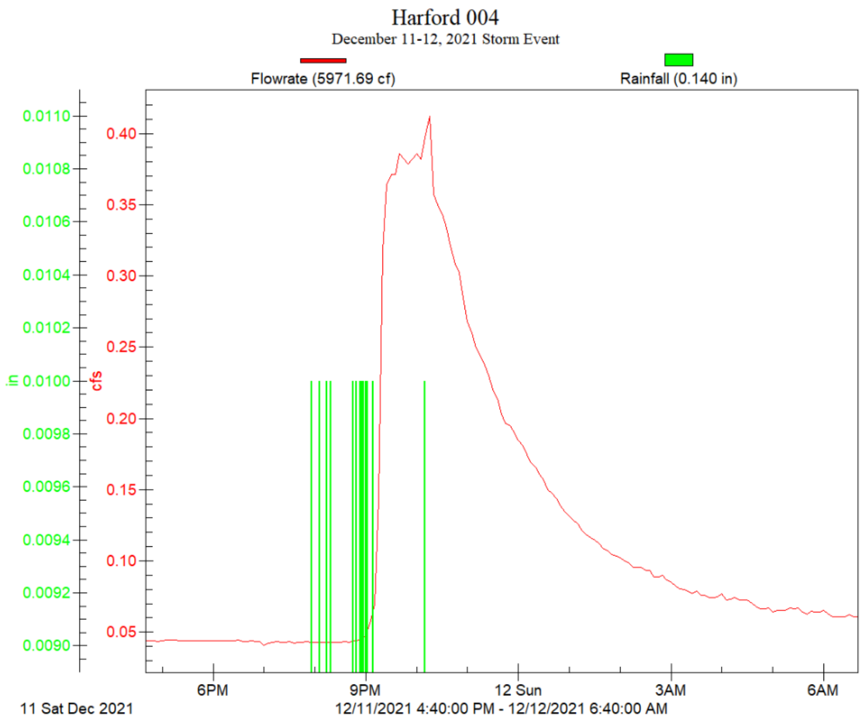

Figure A-3. Hydrograph at Station WC004 for December 11-12, 2021 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb

Constituent	11-12 December, 2021		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	<1	2	<1
Nitrate-Nitrite Nitrogen	1.4	0.8	2.2
Orthophosphate Phosphorus	<0.05	<0.05	<0.05
Solids (Suspended)	<2	24	4
Copper	0.003	0.003	0.003
Lead	<0.001	0.0003	<0.001
Zinc	0.012	0.016	0.021
Ammonia Nitrogen	<0.3	<0.3	0.1
Kjeldahl Nitrogen (Total)	0.5	0.8	0.7
Total Phosphorus	0.02	0.08	0.02
Hardness	176	212	260
Chloride	125	157	153
pH	7.14	7.14	6.89

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb

Constituent	11-12 December, 2021		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	2	2	2
Nitrate-Nitrite Nitrogen	1	0.9	0.5
Orthophosphate Phosphorus	<0.05	<0.05	0.01
Solids (Suspended)	25	18	9
Copper	0.005	0.008	0.006
Lead	0.0003	0.001	0.0006
Zinc	0.02	0.042	0.026
Ammonia Nitrogen	<0.3	<0.3	0.35
Kjeldahl Nitrogen (Total)	0.9	0.8	1
Total Phosphorus	0.06	0.06	0.05
Hardness	168	210	82
Chloride	108	182	62.6
pH	7.16	7.25	7.08

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb

Constituent	11-12 December, 2021		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	5	2	2
Nitrate-Nitrite Nitrogen	0.8	1	0.5
Orthophosphate Phosphorus	0.01	<0.05	<0.05
Solids (Suspended)	5	5	3
Copper	0.006	0.004	0.005
Lead	<0.001	<0.001	0.0004
Zinc	0.015	0.014	0.022
Ammonia Nitrogen	<0.3	<0.3	0.48
Kjeldahl Nitrogen (Total)	0.7	0.6	0.9
Total Phosphorus	0.04	0.02	0.04
Hardness	210	194	80
Chloride	113	156	67.8
pH	7.19	7.35	7.04

Table A-4. Analytical Results – Wheel Creek Grab Sampling			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
December 13, 2021 (Peak)			
TPH (mg/L)	<5.0	<5.0	<5.0
E. coli (MPN/100 ml)	160	20.3	126
Temp (C)	7.6	6.7	8.7
DO (mg/L)	11.86	11.39	9.5
pH	6.94	6.96	6.67
Sp. Cond. (mS/cm)	0.504	0.585	0.925

Table A-5. Rainfall and flow statistics			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
Rainfall (in.)	0.14	0.14	0.14
Duration (hrs.)	10	10	14
Intensity (in./hr.)	0.014	0.014	0.010
Discharge (cf.)	65,437	39,737	5,972

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WHEEL CREEK STORM MONITORING
SUMMARY REPORT
JANUARY 9-10. 2022

INTRODUCTION

Versar field staff traveled to the site on January 8 to deploy siphon samplers and program the SIGMA automated samplers to sample the event. Rainfall initiated at approximately 10:14 a.m. the morning of Sunday, January 9. At the Wheel Creek Rain Gauge Station, 0.25 inches of rain was recorded for the duration of the storm.

On the morning of January 10, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the falling limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on January 10, to composite automated samples and suspended sediment concentration samples (SSC). Siphon samples were submitted to the laboratory for analysis of SSC on January 10. Composite samples were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on January 10.

The following problems occurred during the storm event:

The ISCO bubbler tubing detached at Station WC002 and WC003 due to debris in the pipes. There was frozen precipitation on the rain gauge during the event. Versar field crew used the WC004 hydrograph to composite the storm for those sites. Because of the frozen precipitation Versar crew surmised that the WC004 site received rising flow during the correct rain amounts due to the later water acceptance. WC002 and WC003 showed the rainfall after the flow event.

RESULTS

Hydrographs for the January 9-10 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the January 9 event are shown in Table A-5.

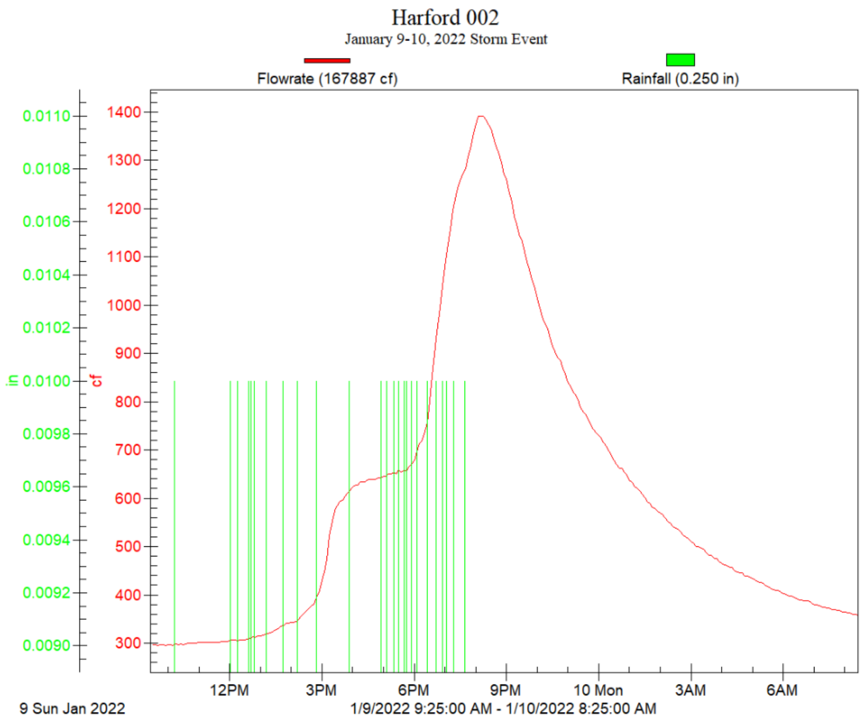

Figure A-1. Hydrograph at Station WC002 for January 9, 2022 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

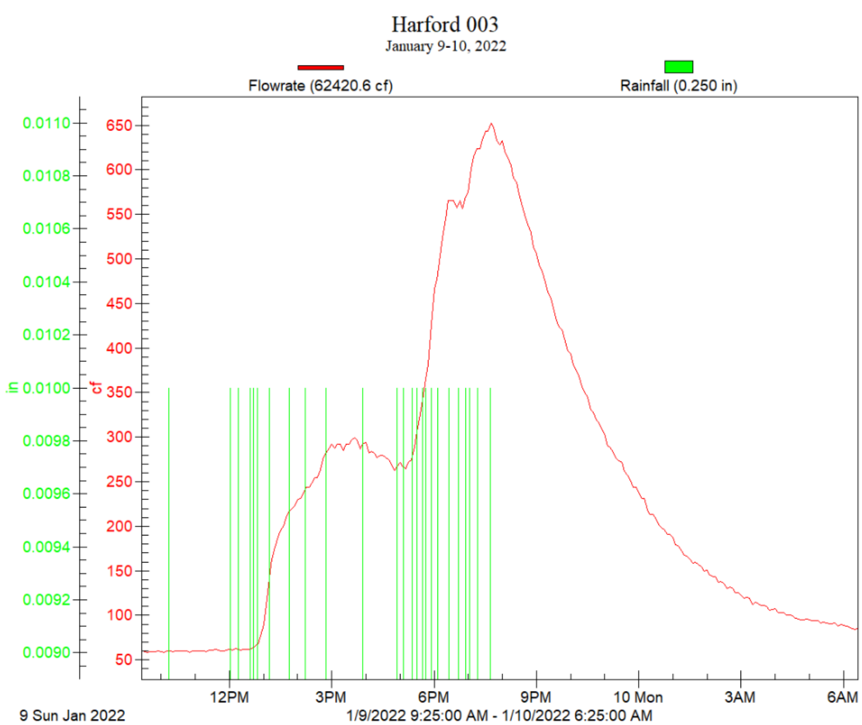

Figure A-2. Hydrograph at Station WC003 for January 9, 2022 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

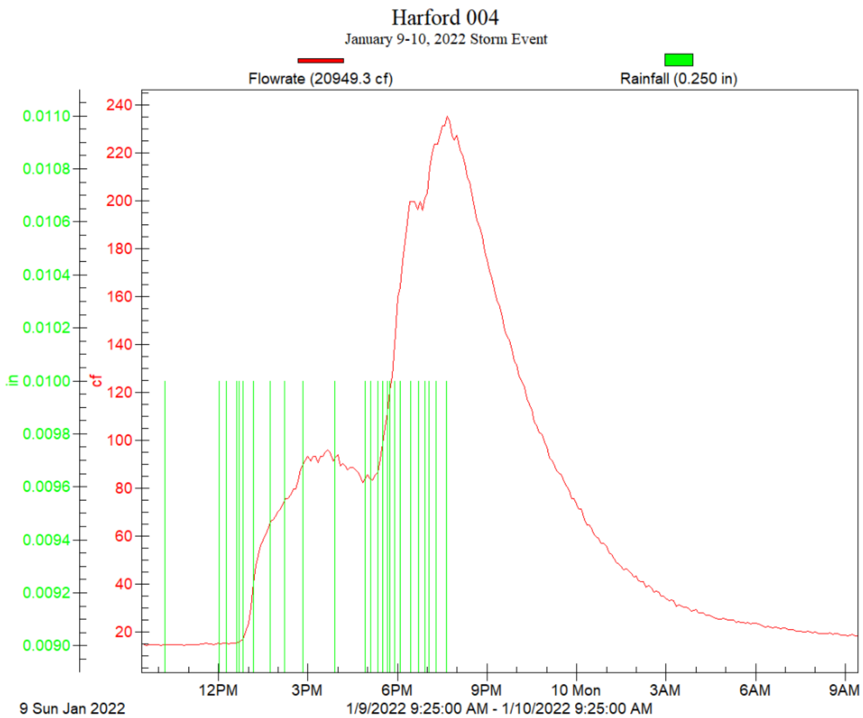

Figure A-3. Hydrograph at Station WC004 for January 9, 2022 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb

Constituent	9-10 January, 2022		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	1	<1	2
Nitrate-Nitrite Nitrogen	1.6	0.9	0.5
Orthophosphate Phosphorus	<0.05	<0.05	0.02
Solids (Suspended)	2	4	10
Copper	0.001	<0.002	0.003
Lead	<0.001	<0.001	0.0003
Zinc	0.022	0.016	0.04
Ammonia Nitrogen	0.13	0.07	0.27
Kjeldahl Nitrogen (Total)	0.5	0.5	1
Total Phosphorus	0.02	<0.05	0.05
Hardness	202	172	127
Chloride	548	240	377
pH	7.08	7.14	6.93

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb			
Constituent	**9-10 January, 2022**		
	Station WC002 (mg/L)	**Station WC003 (mg/L)**	**Station WC004 (mg/L)**
5-Day BOD	3	2	3
Nitrate-Nitrite Nitrogen	0.6	0.5	0.3
Orthophosphate Phosphorus	0.03	0.02	0.03
Solids (Suspended)	16	16	11
Copper	0.006	0.005	0.005
Lead	0.0006	0.0005	0.0008
Zinc	0.044	0.038	0.058
Ammonia Nitrogen	0.28	0.22	0.22
Kjeldahl Nitrogen (Total)	1.1	0.9	1
Total Phosphorus	0.07	0.07	0.06
Hardness	168	186	121
Chloride	1020	731	669
pH	6.97	6.85	6.97

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb			
Constituent	**9-10 January, 2022**		
	Station WC002 (mg/L)	**Station WC003 (mg/L)**	**Station WC004 (mg/L)**
5-Day BOD	2	2	2
Nitrate-Nitrite Nitrogen	0.5	0.4	0.3
Orthophosphate Phosphorus	0.02	0.02	0.02
Solids (Suspended)	8	7	7
Copper	0.005	0.004	0.005
Lead	0.0005	0.0003	0.0005
Zinc	0.038	0.036	0.041
Ammonia Nitrogen	0.17	0.14	0.19
Kjeldahl Nitrogen (Total)	0.9	0.8	0.9
Total Phosphorus	0.05	0.03	0.05
Hardness	133	174	88
Chloride	692	703	456
pH	7.04	6.96	7.05

Table A-4. Analytical Results – Wheel Creek Grab Sampling			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
January 10, 2022 (Falling)			
TPH (mg/L)	<5	<5	<5
E. coli (MPN/100 ml)	387	206	816
Temp (C)	2.4	2.2	4.5
DO (mg/L)	13.03	12.92	11.45
pH	7.09	7.03	6.83
Sp. Cond. (mS/cm)	1.744	1.267	1.161

Table A-5. Rainfall and flow statistics			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
Rainfall (in.)	0.25	0.25	0.25
Duration (hrs.)	23	21	24
Intensity (in./hr.)	0.011	0.012	0.010
Discharge (cf.)	167,887	62,421	20,949

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WHEEL CREEK STORM MONITORING SUMMARY REPORT

JANUARY 20, 2022

INTRODUCTION

Versar field staff traveled to the site on January 19 to deploy siphon samplers and program the SIGMA automated samplers to sample the event. Rainfall initiated at approximately 10:14 a.m. the morning of Wednesday, January 19. At the Wheel Creek Rain Gauge Station, 0.46 inches of rain was recorded for the duration of the storm.

On the morning of January 20, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the falling limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on January 20 to composite automated and suspended sediment concentration samples (SSC). Siphon samples were submitted to the laboratory for analysis of SSC on January 20. Composite samples, including TPH, were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on January 20.

The following issue occurred during the storm event:

The ISCO bubbler line detached from the sensor carrier at Station WC002 and WC003 stations during the storm event due to debris in the pipe. Versar field crew used the WC004 hydrograph to composite the storm at both affected sites.

RESULTS

Hydrographs for the January 20 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the January 20 event are shown in Table A-5.

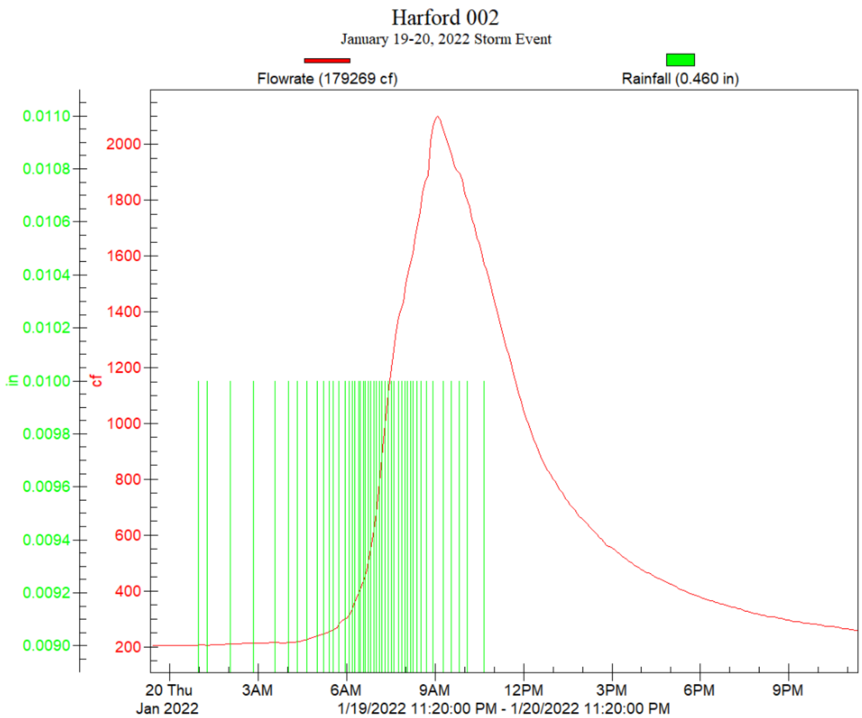

Figure A-1. Hydrograph at Station WC002 for January 20, 2022 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

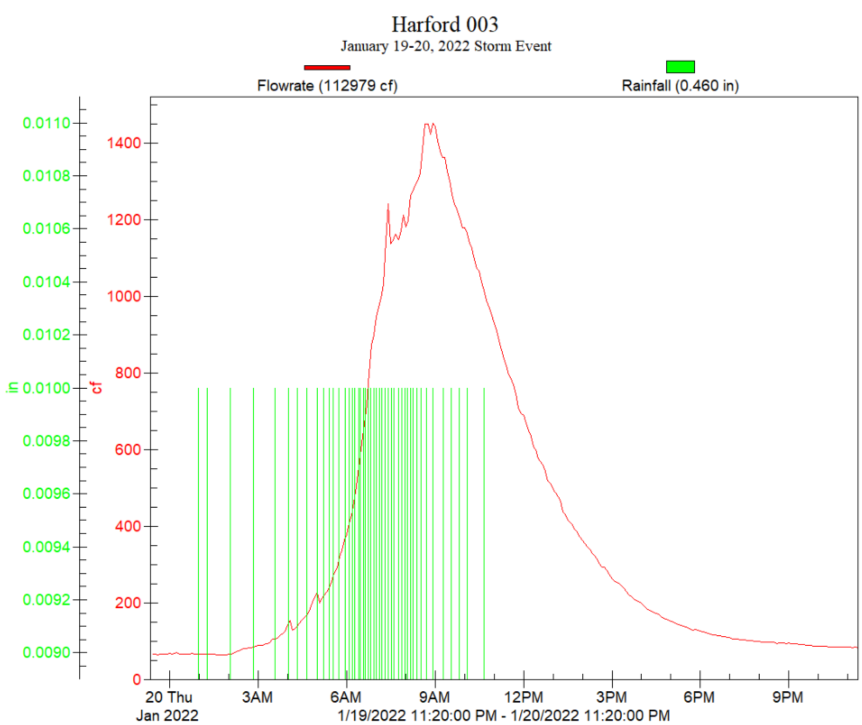

Figure A-2. Hydrograph at Station WC003 for January 20, 2022 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

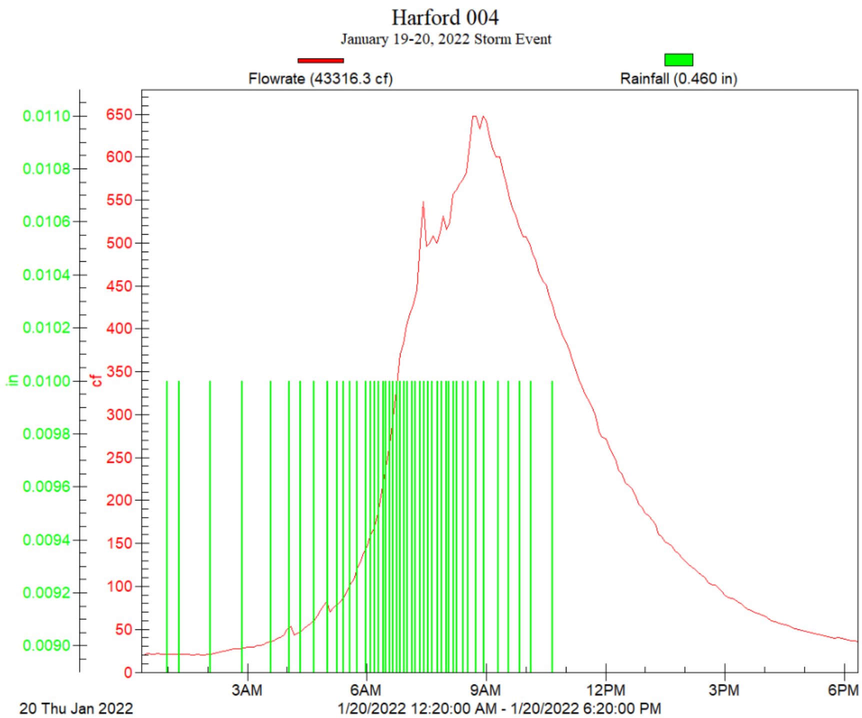

Figure A-3. Hydrograph at Station WC004 for January 20, 2022 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb

Constituent	20 January, 2022		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	<1	2	2
Nitrate-Nitrite Nitrogen	1.6	1.1	1.3
Orthophosphate Phosphorus	<0.05	<0.05	<0.05
Solids (Suspended)	2	3	7
Copper	0.001	0.003	0.004
Lead	<0.001	<0.001	0.0006
Zinc	0.017	0.021	0.026
Ammonia Nitrogen	0.48	0.22	0.08
Kjeldahl Nitrogen (Total)	0.4	0.5	0.7
Total Phosphorus	0.01	0.02	0.03
Hardness	150	168	30
Chloride	206	288	148
pH	6.94	7.13	6.85

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb			
Constituent	**20 January, 2022**		
	Station WC002 (mg/L)	**Station WC003 (mg/L)**	**Station WC004 (mg/L)**
5-Day BOD	3	3	3
Nitrate-Nitrite Nitrogen	0.5	0.4	0.3
Orthophosphate Phosphorus	0.03	0.02	0.03
Solids (Suspended)	18	14	8
Copper	0.009	0.005	0.002
Lead	0.001	0.0006	0.0004
Zinc	0.027	0.023	0.028
Ammonia Nitrogen	0.14	0.18	0.11
Kjeldahl Nitrogen (Total)	0.8	0.8	0.7
Total Phosphorus	0.08	0.06	0.05
Hardness	56	69	167
Chloride	197	253	318
pH	7.07	7.18	7.07

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb			
Constituent	**20 January, 2022**		
	Station WC002 (mg/L)	**Station WC003 (mg/L)**	**Station WC004 (mg/L)**
5-Day BOD	2	2	3
Nitrate-Nitrite Nitrogen	0.5	0.4	0.3
Orthophosphate Phosphorus	0.03	0.02	0.02
Solids (Suspended)	7	6	6
Copper	0.004	0.003	0.003
Lead	0.0004	0.0005	0.0004
Zinc	0.02	0.022	0.031
Ammonia Nitrogen	0.1	0.18	0.12
Kjeldahl Nitrogen (Total)	0.7	0.7	0.8
Total Phosphorus	0.06	0.05	0.04
Hardness	60	66	43
Chloride	181	246	230
pH	7.1	7.15	7.03

Table A-4. Analytical Results – Wheel Creek Grab Sampling			
Constituent	Station WC002	Station WC003	Station WC004
January 20, 2022 (Falling)			
TPH (mg/L)	<5	<5	<5
E. coli (MPN/100 ml)	613	291	579
Temp (C)	3.6	3.2	2.9
DO (mg/L)	13.14	12.88	12.57
pH	7.01	6.92	6.90
Sp. Cond. (mS/cm)	0.708	0.829	0.788

Table A-5. Rainfall and flow statistics			
Constituent	Station WC002	Station WC003	Station WC004
Rainfall (in.)	0.46	0.46	0.46
Duration (hrs.)	24	24	18
Intensity (in./hr.)	0.019	0.019	0.026
Discharge (cf.)	179,269	112,979	43,316

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WHEEL CREEK STORM MONITORING SUMMARY REPORT
MARCH 9, 2022

INTRODUCTION

Versar field staff traveled to the site on March 8 to deploy siphon samplers and program the SIGMA automated samplers to sample the event. Rainfall initiated at approximately 7:20 a.m. the morning of Wednesday, March 9. At the Wheel Creek Rain Gauge Station, 0.37 inches of rain was recorded for the duration of the storm.

On the morning of March 9, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the peak limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

Field staff traveled to the sites on March 10 to composite automated samples. Composite samples, including TPH, were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on March 10. Siphon samples were delivered on March 18, 2022 for SSC analysis.

RESULTS

Hydrographs for the March 9 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the March 9 event are shown in Table A-5.

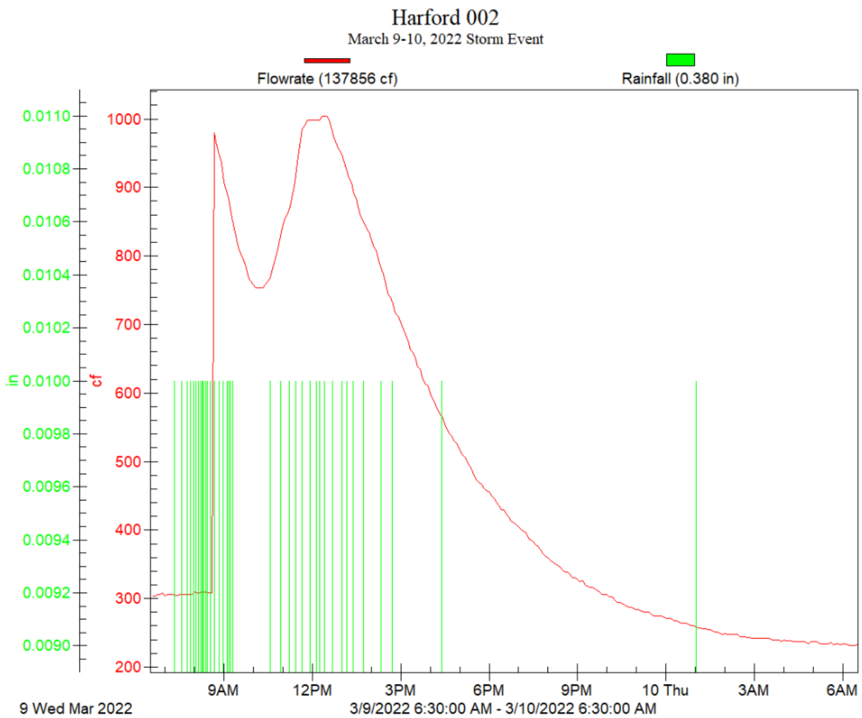

Figure A-1. Hydrograph at Station WC002 for March 9, 2022 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

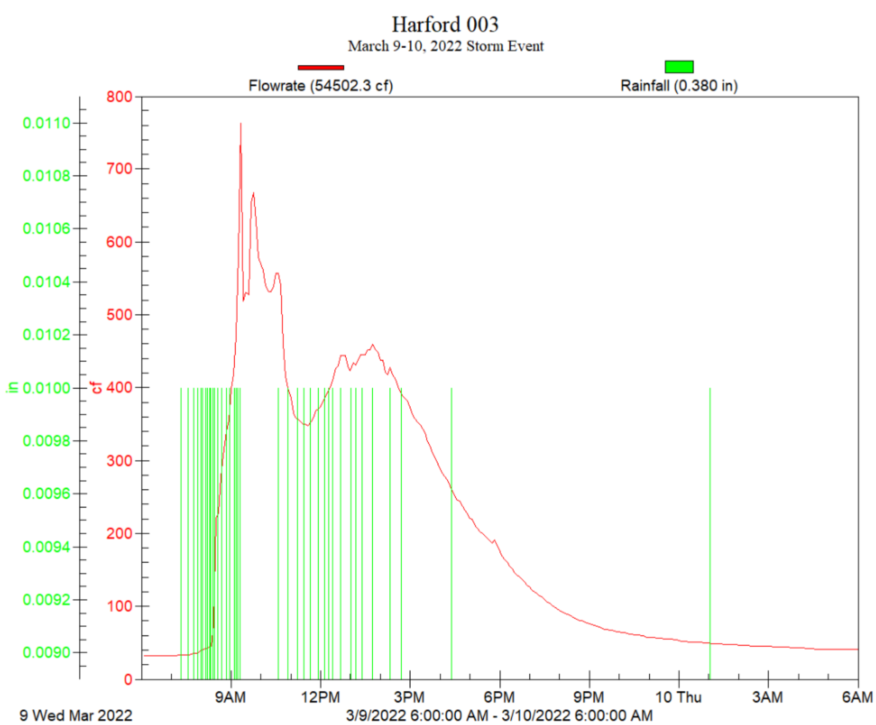

Figure A-2. Hydrograph at Station WC003 for March 9, 2022 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

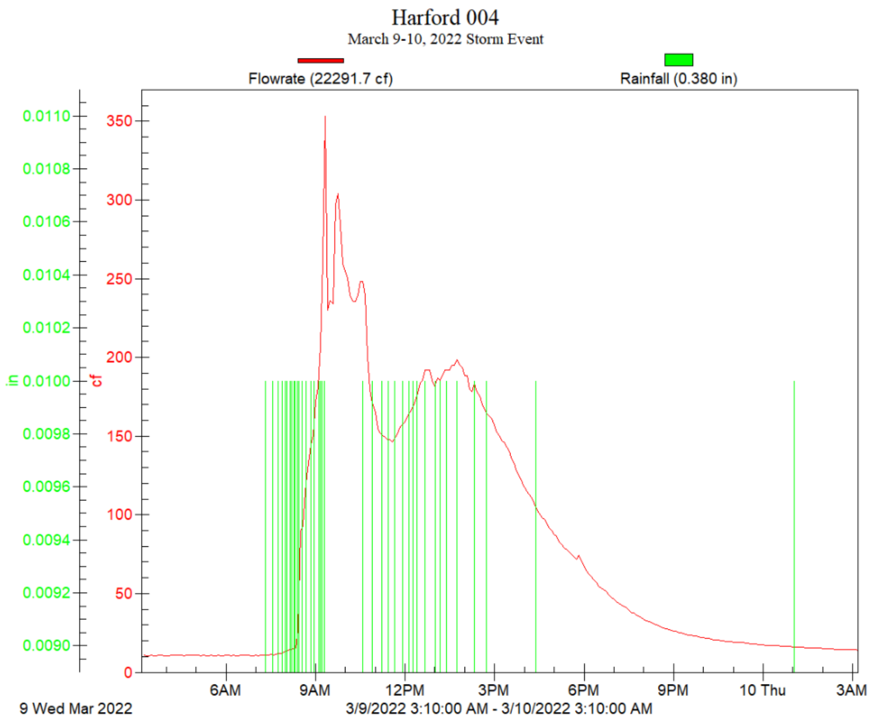

Figure A-3. Hydrograph at Station WC004 for March 9, 2022 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb

Constituent	9 March, 2022		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	1	2	2
Nitrate-Nitrite Nitrogen	1.3	0.9	2.3
Orthophosphate Phosphorus	<0.05	<0.05	0.01
Solids (Suspended)	<2	11	8
Copper	0.002	0.003	0.003
Lead	<0.001	0.0005	0.0003
Zinc	0.014	0.017	0.032
Ammonia Nitrogen	0.07	<0.3	0.08
Kjeldahl Nitrogen (Total)	0.6	0.8	0.8
Total Phosphorus	0.02	0.04	0.03
Hardness	168	208	296
Chloride	183	243	456
pH	7.25	7.32	7.01

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb

Constituent	9 March, 2022		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	3	3	4
Nitrate-Nitrite Nitrogen	0.8	0.6	0.4
Orthophosphate Phosphorus	0.02	0.02	0.02
Solids (Suspended)	14	17	10
Copper	0.005	0.005	0.006
Lead	0.0005	0.0006	0.0007
Zinc	0.02	0.02	0.033
Ammonia Nitrogen	0.09	0.09	0.13
Kjeldahl Nitrogen (Total)	0.9	0.9	1.3
Total Phosphorus	0.05	0.05	0.06
Hardness	120	144	80
Chloride	212	330	382
pH	7.36	7.38	7.38

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb

Constituent	9 March, 2022		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	2	2	2
Nitrate-Nitrite Nitrogen	0.7	0.5	0.6
Orthophosphate Phosphorus	0.02	0.02	<0.05
Solids (Suspended)	<2	<2	<2
Copper	0.004	0.003	0.004
Lead	<0.001	<0.001	<0.001
Zinc	0.015	0.014	0.026
Ammonia Nitrogen	0.06	<0.3	0.05
Kjeldahl Nitrogen (Total)	0.7	0.8	0.9
Total Phosphorus	0.03	0.02	0.04
Hardness	100	130	120
Chloride	201	363	480
pH	7.3	7.36	7.36

Table A-4. Analytical Results – Wheel Creek Grab Sampling			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
March 10, 2022 (Peak)			
TPH (mg/L)	<5	<5	<5
E. coli (MPN/100 ml)	1200	649	93.3
Temp (C)	7.7	7.9	7.9
DO (mg/L)	11.63	11.59	10.52
pH	7.32	7.43	6.94
Sp. Cond. (mS/cm)	0.743	1.132	1.387

Table A-5. Rainfall and flow statistics			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
Rainfall (in.)	0.38	0.38	0.38
Duration (hrs.)	24	24	24
Intensity (in./hr.)	0.016	0.016	0.016
Discharge (cf.)	137,856	54,502	22,292

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WHEEL CREEK STORM MONITORING SUMMARY REPORT

MAY 6-8, 2022

INTRODUCTION

Versar field staff traveled to the site on May 6 to deploy siphon samplers and program the SIGMA automated samplers to sample the event. Rainfall initiated at approximately 6:47 a.m. the morning of Friday, May 6. At a local neighboring rain gauge, 2.95 inches of rain was recorded for the duration of the storm. The Wheel Creek Rain Gauge Station had a clog in the gauge, local rain data from a neighborhood rain gauge was used for the storm total.

On the morning of May 6, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the rising limb of the storm. Field staff also collected the rising limb grab for the storm due to the faster than anticipated forecast. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

On the morning of May 9, field staff traveled to the sites to composite automated samples. Composite samples, including TPH, were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on May 9. Siphon samples were delivered to Enviro-Chem Laboratories for analysis of SSC on May 10, 2022.

The following issue occurred during the storm event:

The Versar Rain Gauge had a clog in it during the storm, so a neighborhood rain gauge was used for the complete rain fall total of the storm. The clog resulted in a trickle discharge being recorded, which is why the recorded rainfall shown in the hydrographs is less than the overall recorded for the event; the rest of the rainfall was recorded after flows normalized and the clog was cleared, and is not included in the storm hydrographs.

RESULTS

Hydrographs for the May 6-8 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the May 6-8 event are shown in Table A-5.

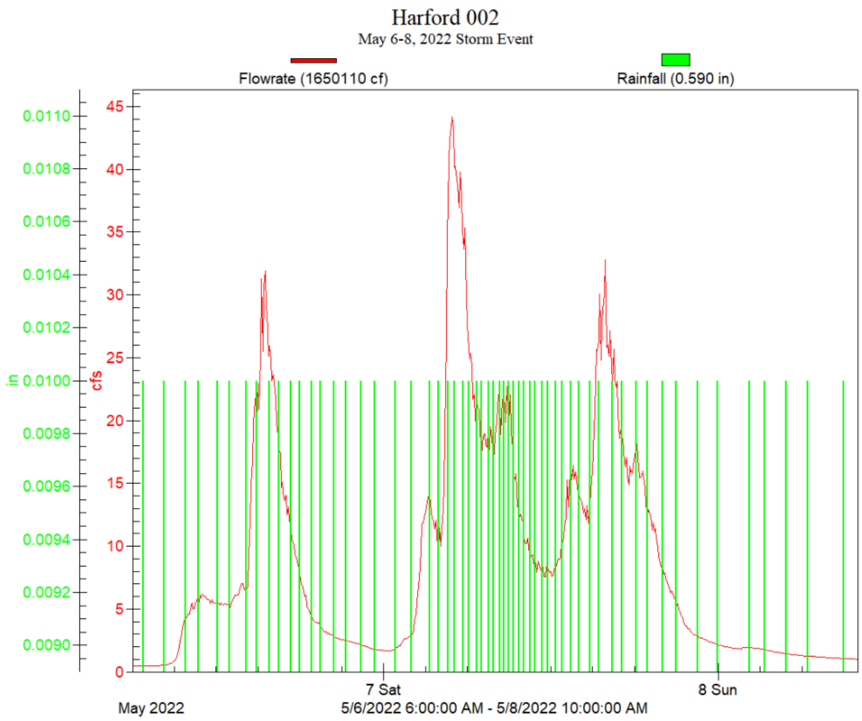

Figure A-1. Hydrograph at Station WC002 for May 6-8, 2022 storm. Rainfall data source: LMD BELAI 131.

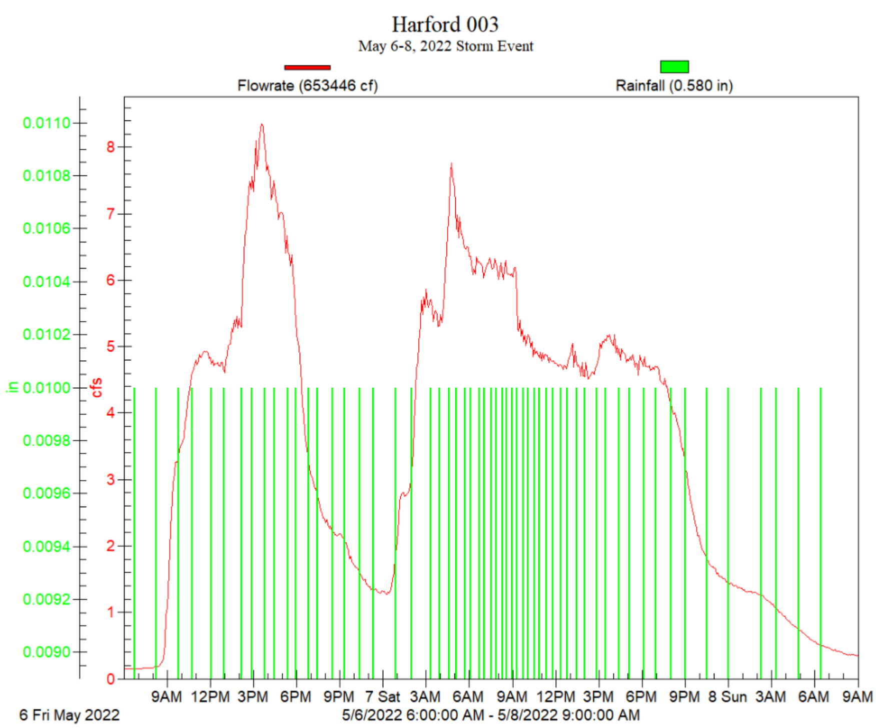

Figure A-2. Hydrograph at Station WC003 for May 6-8, 2022 storm. Rainfall data source: Rainfall data source: LMD BELAI 131.

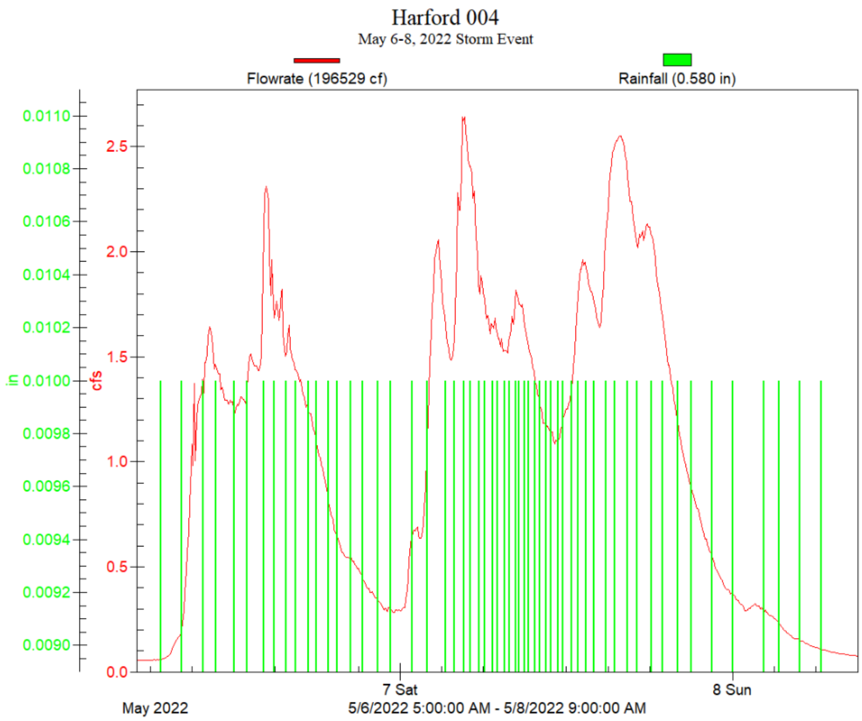

Figure A-3. Hydrograph at Station WC004 for May 6-8, 2022 storm. Rainfall data source: Rainfall data source: LMD BELAI 131.

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb

Constituent	6-8 May, 2022		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	3	3	3
Nitrate-Nitrite Nitrogen	0.6	0.6	0.4
Orthophosphate Phosphorus	0.01	<0.05	0.02
Solids (Suspended)	21	19	5
Copper	0.004	0.01	0.008
Lead	0.0006	0.002	0.001
Zinc	0.018	0.051	0.044
Ammonia Nitrogen	0.17	0.11	0.16
Kjeldahl Nitrogen (Total)	1.4	1.7	1.6
Total Phosphorus	0.18	0.17	0.1
Hardness	92	128	42
Chloride	81.4	144	45.4
pH	6.76	6.85	7

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb			
Constituent	6-8 May, 2022		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	2	2	1
Nitrate-Nitrite Nitrogen	0.3	0.2	0.2
Orthophosphate Phosphorus	0.03	0.02	0.03
Solids (Suspended)	10	8	8
Copper	0.009	0.008	0.006
Lead	0.0007	0.0007	0.0005
Zinc	0.02	0.017	0.017
Ammonia Nitrogen	<0.3	0.06	<0.3
Kjeldahl Nitrogen (Total)	1	1	0.9
Total Phosphorus	0.07	0.06	0.04
Hardness	34	36	26
Chloride	17.7	33.8	17.2
pH	7.02	7.09	7.1

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb			
Constituent	6-8 May, 2022		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	1	1	<1
Nitrate-Nitrite Nitrogen	0.5	0.3	0.4
Orthophosphate Phosphorus	0.02	<0.05	0.01
Solids (Suspended)	5	8	5
Copper	0.008	0.009	0.006
Lead	<0.002	0.0006	0.0004
Zinc	0.021	0.019	0.019
Ammonia Nitrogen	0.07	<0.3	<0.3
Kjeldahl Nitrogen (Total)	0.9	0.9	0.9
Total Phosphorus	0.05	0.04	0.03
Hardness	64	50	42
Chloride	37.6	39.5	48.4
pH	6.93	7.08	6.88

Table A-4. Analytical Results – Wheel Creek Grab Sampling			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
May 9, 2022 (Rising)			
TPH (mg/L)	<5	<5	<5
E. coli (MPN/100 ml)	>2420	>2420	>2420
Temp (C)	14.1	14.1	14.8
DO (mg/L)	9.34	9.48	8.43
pH	6.85	6.94	6.94
Sp. Cond. (mS/cm)	0.339	0.534	0.203

Table A-5. Rainfall and flow statistics			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
Rainfall (in.)	2.95	2.95	2.95
Duration (hrs.)	52	51	52
Intensity (in./hr.)	0.057	0.058	0.057
Discharge (cf.)	1,650,110	653,446	196,529

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WHEEL CREEK STORM MONITORING
SUMMARY REPORT
MAY 18-19, 2022

INTRODUCTION

Versar field staff traveled to the site on May 18 to deploy siphon samplers and program the SIGMA automated samplers to sample the event. Rainfall initiated at approximately 22:16 p.m. the evening of Wednesday, May 18. At the Wheel Creek Rain Gauge Station, 0.37 inches of rain was recorded for the duration of the storm.

On the morning of May 19, field staff collected grab water samples to be tested for TPH and *E. coli* at all three stations that coincided with the falling limb of the storm. The *E. coli* samples were submitted to Enviro-Chem Laboratories for analysis shortly after collection.

On the morning of May 19, field staff traveled to the sites to composite automated samples. Composite samples, including TPH, were transported to the Harford County Government Department of Public Works Water and Sewer Laboratories on May 19. Siphon samples were delivered to Enviro-Chem Laboratories for analysis of SSC on May 19, 2022.

The following issue occurred during the storm event:

The ISCO bubbler line detached from the sensor carrier at Station WC002 and WC003 stations during the storm event due to debris in the pipe. Versar field crew used the WC004 hydrograph to composite the storm at both affected sites.

RESULTS

Hydrographs for the May 18-19 storm are presented in Figures A-1 through A-3 below. Laboratory analytical and field water quality results for the storm are shown in Tables A-1 through A-4. Rainfall and flow statistics for the May 18-19 event are shown in Table A-5.

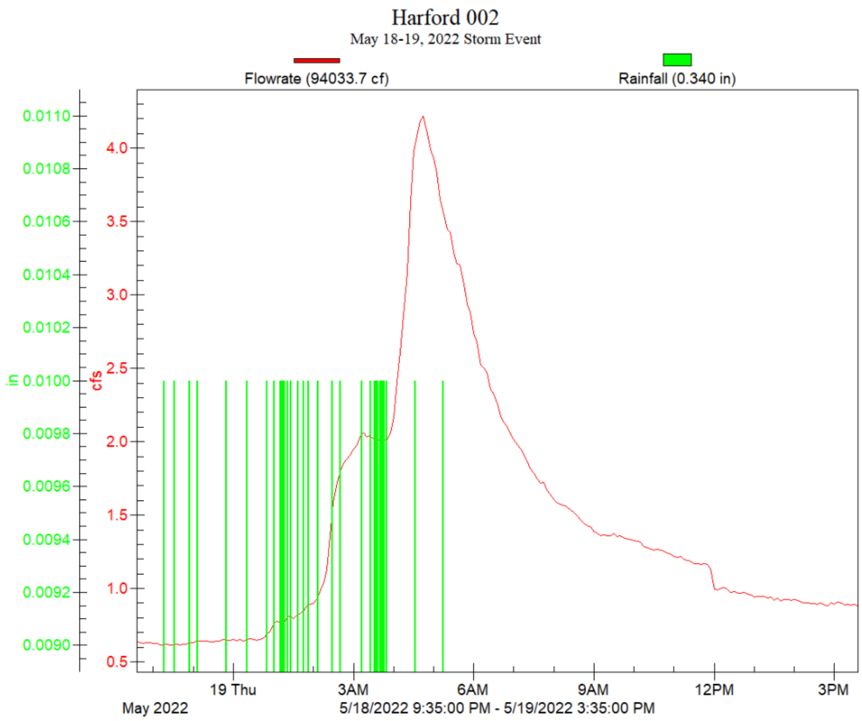

Figure A-1. Hydrograph at Station WC002 for May 18-19, 2022 storm. Wheel Creek Rain Gauge Station.

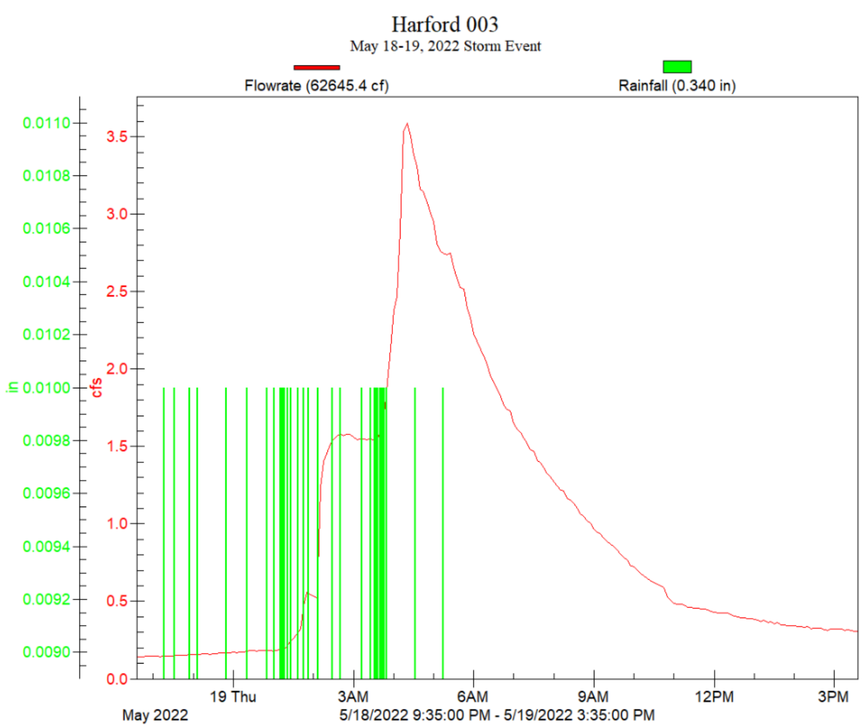

Figure A-2. Hydrograph at Station WC003 for May 18-19, 2022 storm. Rainfall data source: Rainfall data source: Wheel Creek Rain Gauge Station.

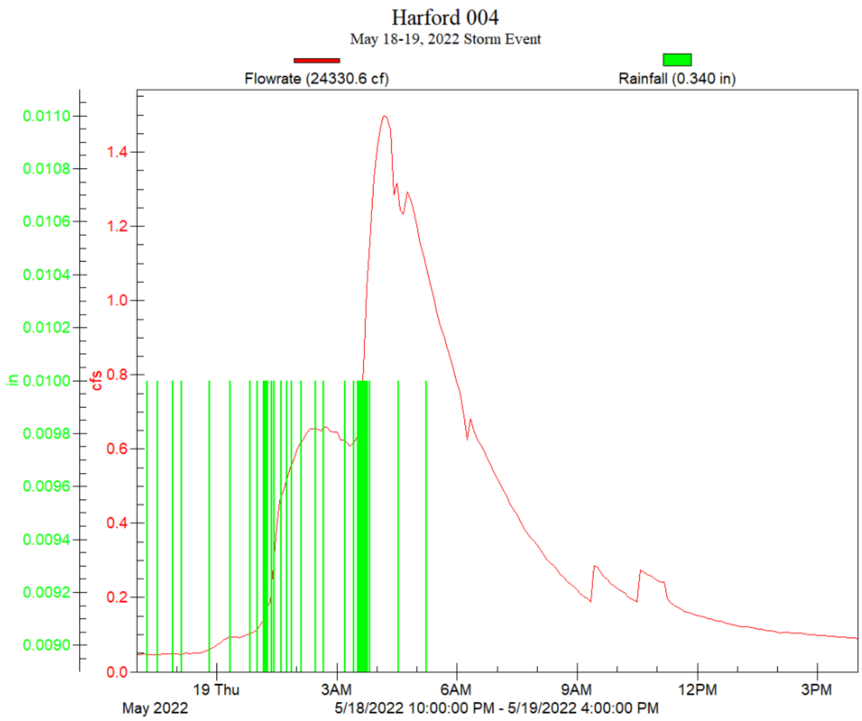

Figure A-3. Hydrograph at Station WC004 for May 18-19, 2022 storm. Rainfall data source: Wheel Creek Rain Gauge Station.

Table A-1. Analytical results – Wheel Creek automated sampling, Rising Limb

Constituent	18-19 May, 2022		
	Station WC002 (mg/L)	Station WC003 (mg/L)	Station WC004 (mg/L)
5-Day BOD	2	3	3
Nitrate-Nitrite Nitrogen	1.4	0.8	1.6
Orthophosphate Phosphorus	<0.05	<0.05	0.01
Solids (Suspended)	8	26	28
Copper	<0.002	0.003	0.003
Lead	<0.001	0.001	0.0007
Zinc	0.012	0.027	0.032
Ammonia Nitrogen	0.12	0.19	0.11
Kjeldahl Nitrogen (Total)	0.7	1.3	1.2
Total Phosphorus	0.03	0.06	0.06
Hardness	176	156	212
Chloride	128	150	187
pH	7	6.82	6.69

Table A-2. Analytical results – Wheel Creek automated sampling, Peak Limb			
Constituent	**18-19 May, 2022**		
	Station WC002 (mg/L)	**Station WC003 (mg/L)**	**Station WC004 (mg/L)**
5-Day BOD	6	3	5
Nitrate-Nitrite Nitrogen	0.7	0.5	0.6
Orthophosphate Phosphorus	0.02	<0.05	0.02
Solids (Suspended)	39	10	21
Copper	0.005	0.004	0.006
Lead	0.001	0.0005	0.001
Zinc	0.029	0.018	0.032
Ammonia Nitrogen	0.44	0.26	0.39
Kjeldahl Nitrogen (Total)	1.6	1.3	1.8
Total Phosphorus	0.11	0.05	0.08
Hardness	88	84	80
Chloride	62	83.9	51.4
pH	7.06	7.05	6.92

Table A-3. Analytical results – Wheel Creek automated sampling, Falling Limb			
Constituent	**18-19 May, 2022**		
	Station WC002 (mg/L)	**Station WC003 (mg/L)**	**Station WC004 (mg/L)**
5-Day BOD	4	2	4
Nitrate-Nitrite Nitrogen	0.6	0.5	0.5
Orthophosphate Phosphorus	<0.05	<0.05	<0.05
Solids (Suspended)	8	6	12
Copper	0.002	<0.002	0.005
Lead	<0.001	<0.001	0.0004
Zinc	0.013	0.011	0.025
Ammonia Nitrogen	0.33	0.13	0.33
Kjeldahl Nitrogen (Total)	1.2	0.9	1.4
Total Phosphorus	0.05	0.03	0.04
Hardness	68	124	64
Chloride	52	111	59.3
pH	7.02	6.95	6.73

Table A-4. Analytical Results – Wheel Creek Grab Sampling			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
May 19, 2022 (Falling)			
TPH (mg/L)	<5	<5	<5
E. coli (MPN/100 ml)	1730	1990	921
Temp (C)	17.7	17.3	16.9
DO (mg/L)	8.93	8.65	6.14
pH	7.01	7.22	6.84
Sp. Cond. (mS/cm)	0.338	0.538	1.361

Table A-5. Rainfall and flow statistics			
Constituent	**Station WC002**	**Station WC003**	**Station WC004**
Rainfall (in.)	0.34	0.34	0.34
Duration (hrs.)	18	18	18
Intensity (in./hr.)	0.019	0.019	0.019
Discharge (cf.)	94,034	62,645	24,330

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APPENDIX B

RATING CURVES

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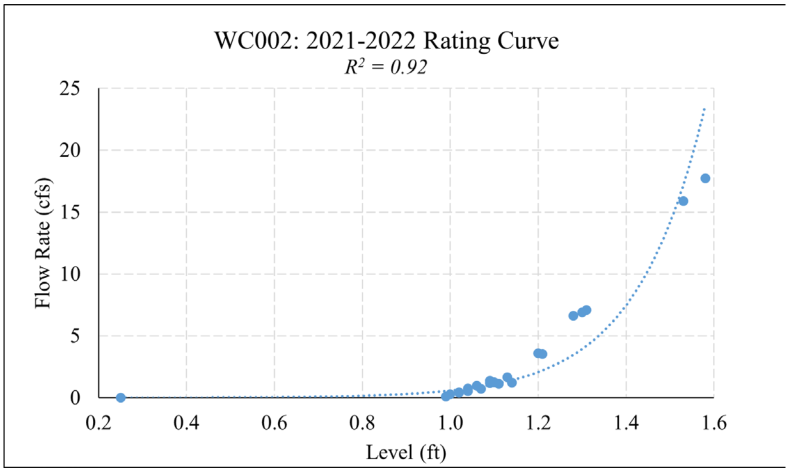
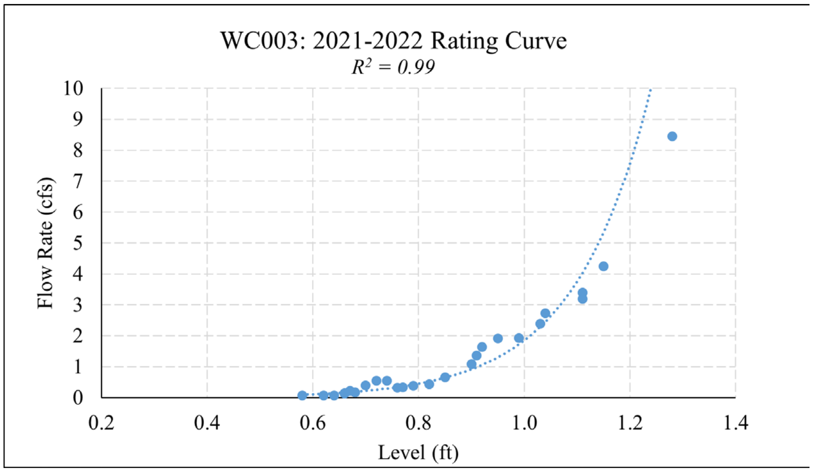
Table B-1. Station WC002 subset rating curve from data points collected in 2021-2022	
Level (ft)	**Flow Rate (cfs)**
0.25	0.010
0.99	0.091
1.00	0.295
1.02	0.422
1.04	0.764
1.07	0.727
1.09	1.189
1.11	1.146
1.13	1.646
1.21	3.531
1.28	6.631
1.30	6.906
1.53	15.892
1.58	17.736

Table B-2. Station WC003 subset rating curve from data points collected in 2021-2022	
Level (ft)	**Flow Rate (cfs)**
0.58	0.067
0.66	0.154
0.70	0.397
0.79	0.389
0.82	0.439
0.85	0.664
0.90	1.093
0.92	1.637
0.99	1.929
1.03	2.389
1.04	2.726
1.11	3.189
1.15	4.250
1.28	8.454

Table B-3. Station WC004 subset rating curve from data points collected in 2021-2022	
Level (ft)	**Flow Rate (cfs)**
0.43	0.010
0.54	0.032
0.56	0.037
0.58	0.216
0.61	0.311
0.64	0.281
0.79	1.023
0.89	2.063
0.92	2.308
0.95	2.770
0.96	2.895
1.00	3.623
1.17	6.878
1.20	7.914





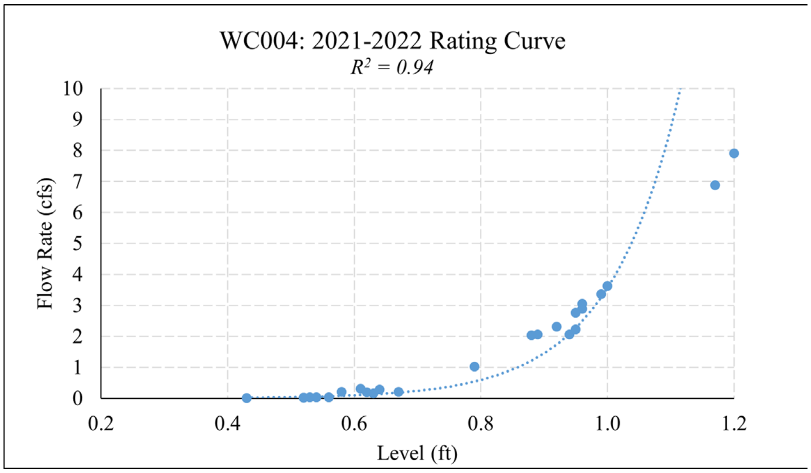


Figure B-1. Rating Curves for Stations WC002, WC003, and WC004

APPENDIX C

RAINFALL TOTALS

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Table C-1. July 2021 – June 2022 rainfall data from USGS Atkisson logger (inches)												
Day	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**
1	1.19	0.22	4.37	0	0	0.01	0.87	0	0	0.14	0.26	0
2	0.05	0.01	0	0	0.1	0	0.25	0	0	0	0	0.01
3	0.02	0	0	0	0	0	0	0.47	0	0	0	0
4	0	0	0	0	0	0	0	0.64	0	0	0.41	0
5	0	0	0.04	0	0	0	0	0	0	0.31	0	0
6	0	0	0	0	0	0.04	0	0	0.05	0.82	1.15	0
7	0	0	0	0	0	0	0	0.04	0.02	0.83	1.62	0.15
8	0.17	0	0.46	0	0	0	0.01	0	0	0.03	0.05	0.8
9	0	0.02	0.24	0	0	0	0.33	0	0.38	0.07	0	0.44
10	0	0.07	0	0.01	0	0.01	0	0	0	0	0	0
11	0	0.2	0	0	0	0.12	0	0	0	0	0	0.04
12	1.53	0	0	0	1.06	0	0	0	0.54	0.01	0	0.04
13	0	0.05	0	0.01	0.02	0	0	0.16	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0.08	0.28
15	0	0	0.45	0	0.01	0	0	0	0	0	0	0
16	0	0.1	0.03	0.19	0	0	0.67	0	0	0.02	0.03	0.09
17	0.57	0.13	0.01	0	0	0	0.42	0.04	0.14	0	0	0
18	0	0.24	0	0	0.04	0.01	0	0.11	0	1.68	0.03	0
19	0	0	0	0	0	0.01	0	0	0	0.04	0.35	0
20	0	0.94	0	0	0	0	0.48	0	0	0	0	0
21	0	0	0	0	0	0.16	0	0	0	0	0	0
22	0	0.64	0.02	0	0.1	0.14	0	0.05	0	0	0.6	0.52
23	0	0.53	3.28	0.05	0	0	0	0	0.37	0	0	1.21
24	0	0	0	0.01	0	0	0	0.1	0.41	0	0.16	0
25	0.13	0	0	1.14	0	0.02	0	0.55	0	0	0	0
26	0	0	0	0.03	0.11	0	0	0	0.02	0.1	0	0
27	0	0.03	0	0	0	0.07	0	0	0	0	0.54	0.29
28	0	0	0.01	0	0	0.02	0	0	0	0	0.02	0
29	0.17	0	0	2.11	0	0.01	0		0	0	0	0
30	0	0	0	0.06	0	0.26	0		0	0	0	0
31	0	0.01		0		0.01	0.01		0.06		0	
Total Rain	**3.83**	**3.19**	**8.91**	**3.61**	**1.44**	**0.89**	**3.04**	**2.16**	**1.99**	**4.05**	**5.30**	**3.87**
											Annual Rainfall Total:	**42.28**

Table C-2. July 2021 – June 2022 rainfall data from Wheel Creek HOBO logger (inches)												
Day	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**
1	1.03	0.29	4.30	0.00	0.00	0.01	0.81	0.00	0.00	0.12	0.02	0.00
2	0.04	0.00	0.00	0.00	0.09	0.00	0.10	0.00	0.00	0.00	0.03	0.00
3	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.45	0.00	0.00	0.00	0.00
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.67	0.00	0.00	0.06	0.00
5	0.00	0.00	0.04	0.00	0.00	0.00	0.16	0.00	0.00	0.40	0.05	0.00
6	0.00	0.00	0.00	0.00	0.00	0.02	0.01	0.00	0.04	0.65	0.20	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.75	0.36	0.14
8	0.17	0.00	0.56	0.00	0.00	0.00	0.00	0.00	0.00	0.09	0.09	0.85
9	0.00	0.00	0.26	0.00	0.00	0.00	0.25	0.00	0.37	0.06	1.80	0.17
10	0.00	0.07	0.00	0.01	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00
11	0.00	0.26	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.04
12	1.45	0.00	0.00	0.00	0.90	0.00	0.00	0.00	0.42	0.00	0.00	0.04
13	0.00	0.05	0.00	0.00	0.02	0.00	0.00	0.00	0.04	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.28
15	0.00	0.00	0.47	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00
16	0.00	0.11	0.01	0.19	0.00	0.00	0.81	0.05	0.00	0.01	0.02	0.09
17	0.52	0.09	0.01	0.00	0.00	0.00	0.28	0.03	0.13	0.00	0.00	0.00
18	0.01	0.31	0.00	0.00	0.03	0.00	0.00	0.09	0.01	0.58	0.05	0.00
19	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.97	0.29	0.00
20	0.00	0.90	0.00	0.00	0.00	0.00	0.46	0.00	0.00	0.01	0.00	0.00
21	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00	0.00
22	0.00	0.55	0.00	0.00	0.09	0.14	0.00	0.04	0.00	0.00	0.46	0.33
23	0.00	0.50	3.04	0.07	0.00	0.00	0.00	0.00	0.40	0.00	0.00	1.05
24	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.08	0.26	0.00	0.15	0.00
25	0.21	0.00	0.00	1.26	0.00	0.02	0.00	0.48	0.01	0.00	0.00	0.00
26	0.00	0.00	0.00	0.02	0.11	0.00	0.00	0.00	0.01	0.07	0.00	0.00
27	0.00	0.03	0.00	0.01	0.00	0.06	0.00	0.00	0.00	0.00	0.51	0.29
28	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.02	0.00
29	0.18	0.00	0.00	1.97	0.00	0.01	0.00		0.00	0.00	0.00	0.00
30	0.00	0.00	0.00	0.05	0.00	0.27	0.00		0.00	0.00	0.00	0.00
31	0.00	0.01		0.00		0.01	0.03		0.05		0.00	
Total Rain	**3.62**	**3.18**	**8.69**	**3.59**	**1.25**	**0.89**	**2.91**	**2.01**	**1.75**	**3.71**	**4.18**	**3.28**
Annual Rainfall Total:												**39.06**

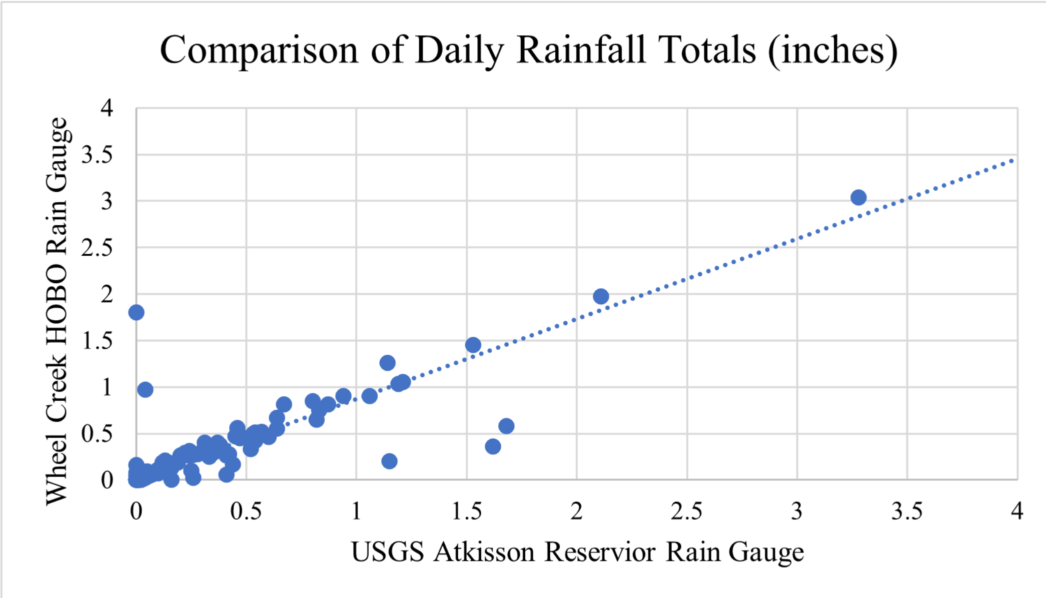

Figure C-1. Comparison of Daily Rainfall Totals for the USGS and Wheel Creek gauges

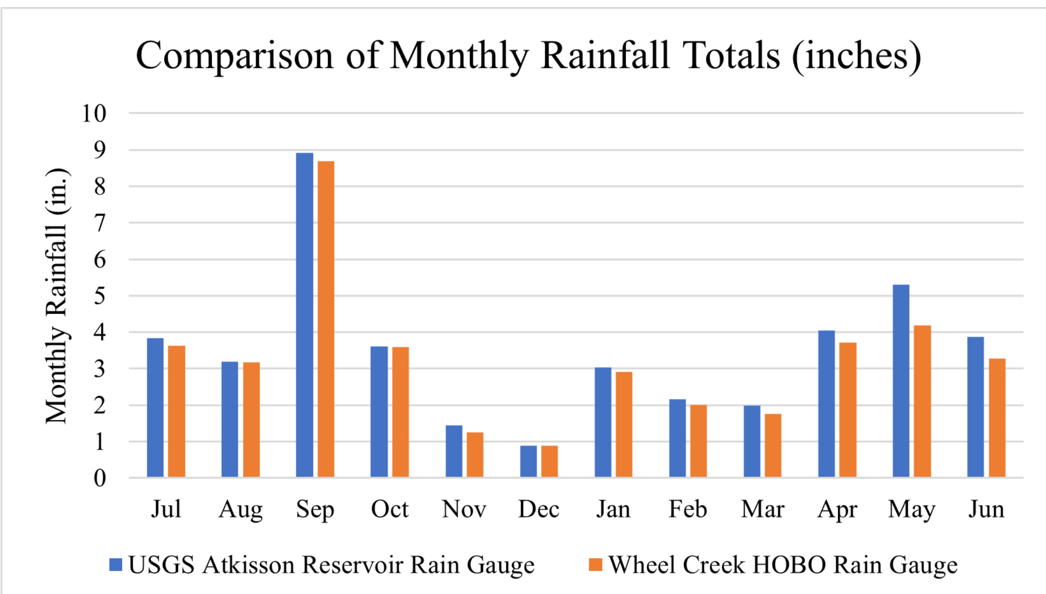

Figure C-2. Comparison of Monthly Rainfall Totals for the USGS and Wheel Creek gauges.

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APPENDIX D

TOTAL ANNUAL LOADS AND YIELDS OF POLLUTANTS AT WHEEL CREEK STUDY STATIONS

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Table D-1. Baseflow and storm flow MCs and EMCs, total annual loads, and annual yields (July 2021-June 2022)

Analyte	Station	Storm EMC (mg/L)	Baseflow MC (mg/L)	Annual Storm Load (lbs)	Annual Baseflow Load (lbs)	Annual Total Load (lbs)	Yield (lbs/ac/yr)
Ammonia	WC002	0.113	0.273	169.254	326.364	495.618	1.478
	WC003	0.102	0.102	69.923	20.889	90.812	0.780
	WC004	0.136	0.043	38.005	3.026	41.031	1.052
BOD	WC002	2.646	1.083	3,973.657	1,293.517	5,267.174	15.709
	WC003	2.300	1.000	1,569.233	205.464	1,774.697	15.247
	WC004	3.208	1.000	894.023	69.836	963.859	24.714
Chloride	WC002	182.844	142.125	274,611.024	169,699.520	444,310.544	1,325.113
	WC003	193.912	167.858	132,294.800	34,488.830	166,783.630	1,432.849
	WC004	178.462	274.333	49,739.059	19,158.236	68,897.296	1,766.597
Nitrate + Nitrite	WC002	0.756	1.283	1,134.884	1,532.320	2,667.204	7.955
	WC003	0.506	0.917	345.317	188.342	533.659	4.585
	WC004	0.430	2.517	119.779	175.753	295.532	7.578
TKN	WC002	0.913	0.600	1,371.163	716.410	2,087.573	6.226
	WC003	0.966	0.608	658.903	124.991	783.894	6.734
	WC004	0.998	0.750	278.212	52.377	330.589	8.477
Total P	WC002	0.085	0.037	127.979	43.781	171.759	0.512
	WC003	0.070	0.027	48.090	5.479	53.569	0.460
	WC004	0.058	0.049	16.233	3.434	19.667	0.504
Ortho-phosphate	WC002	0.033	0.044	50.204	52.736	102.939	0.307
	WC003	0.036	0.050	24.764	10.273	35.037	0.301
	WC004	0.034	0.047	9.535	3.259	12.794	0.328
TSS	WC002	17.813	4.333	26,752.491	5,174.069	31,926.561	95.218
	WC003	12.657	5.500	8,635.351	1,130.052	9,765.403	83.895
	WC004	9.301	3.417	2,592.226	238.605	2,830.831	72.585
Copper	WC002	6.206	0.258	9.321	0.308	9.630	0.029
	WC003	4.562	0.733	3.112	0.151	3.263	0.028
	WC004	5.425	1.025	1.512	0.072	1.583	0.041
Lead	WC002	1.042	0.787	1.565	0.939	2.504	0.007
	WC003	0.630	0.716	0.430	0.147	0.577	0.005
	WC004	0.726	0.765	0.202	0.053	0.256	0.007
Zinc	WC002	21.559	10.000	32.380	11.940	44.320	0.132
	WC003	19.040	10.250	12.990	2.106	15.096	0.130
	WC004	27.222	20.250	7.587	1.414	9.001	0.231

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APPENDIX E

TOTAL SEASONAL LOADS OF POLLUTANTS AT WHEEL CREEK STUDY STATIONS

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Table E-1. Baseflow and storm flow MCs and EMCs and total seasonal load (July 2021-June 2022)

Sample Year	Season	Station	Storm EMC (mg/L)	Baseflow MC (mg/L)	Seasonal Storm Load (lbs)	Seasonal Baseflow Load (lbs)	Seasonal Total Load (lbs)
Ammonia							
2021	Summer	WC002	0.089	0.277	52.356	71.940	124.296
		WC003	0.083	0.113	25.932	5.577	31.509
		WC004	0.032	0.063	4.444	1.068	5.512
	Fall	WC002	-	0.353	-	170.779	170.779
		WC003	-	0.107	-	5.753	5.753
		WC004	0.315	0.070	8.835	1.393	10.228
2022	Winter	WC002	0.149	0.230	29.958	59.323	89.281
		WC003	0.139	0.093	13.033	5.291	18.323
		WC004	0.148	0.040	5.589	0.693	6.283
	Spring	WC002	0.130	0.233	43.399	44.970	88.369
		WC003	0.113	0.093	17.468	4.259	21.728
		WC004	0.134	-	10.094	-	10.094
BOD							
2021	Summer	WC002	2.390	1.333	1,404.761	346.698	1,751.459
		WC003	1.675	1.000	526.435	49.210	575.645
		WC004	4.807	1.000	662.509	16.869	679.377
	Fall	WC002	2.669	1.000	1,010.965	483.338	1,494.303
		WC003	2.000	1.000	240.098	53.932	294.030
		WC004	1.731	1.000	48.578	19.905	68.483
2022	Winter	WC002	2.421	1.000	487.903	257.925	745.827
		WC003	2.413	1.000	225.701	56.688	282.389
		WC004	3.008	1.000	113.335	17.337	130.672
	Spring	WC002	3.034	1.000	1,012.334	192.730	1,205.064
		WC003	2.704	1.000	417.505	45.635	463.139
		WC004	2.834	1.000	212.919	15.725	228.643
Chloride							
2021	Summer	WC002	62.994	94.167	37,031.068	24,485.526	61,516.594
		WC003	76.352	110.767	23,993.733	5,450.797	29,444.531
		WC004	56.551	174.333	7,793.865	2,940.787	10,734.652
	Fall	WC002	115.325	126.667	43,684.972	61,222.832	104,907.805
		WC003	165.518	153.333	19,870.258	8,269.513	28,139.771
		WC004	88.244	329.333	2,477.143	6,555.306	9,032.449
2022	Winter	WC002	410.820	223.333	82,789.832	57,603.207	140,393.039
		WC003	402.942	265.333	37,694.259	15,041.220	52,735.480
		WC004	418.075	309.333	15,752.184	5,363.024	21,115.209
	Spring	WC002	57.273	124.333	19,112.912	23,962.730	43,075.642
		WC003	72.720	142.000	11,227.346	6,480.108	17,707.454
		WC004	50.197	284.333	3,771.754	4,471.060	8,242.814

Table E-1. (Continued)							
Sample Year	**Season**	**Station**	**Storm EMC (mg/L)**	**Baseflow MC (mg/L)**	**Seasonal Storm Load (lbs)**	**Seasonal Baseflow Load (lbs)**	**Seasonal Total Load (lbs)**
Nitrate + Nitrite							
2021	Summer	WC002	0.553	1.233	324.925	320.695	645.621
		WC003	0.390	1.000	122.682	49.210	171.892
		WC004	0.175	1.667	24.133	28.115	52.248
	Fall	WC002	1.066	1.333	403.914	644.451	1,048.365
		WC003	0.899	0.967	107.947	52.134	160.081
		WC004	0.958	3.167	26.896	63.032	89.927
2022	Winter	WC002	0.722	1.467	145.494	378.290	523.783
		WC003	0.538	1.033	50.372	58.578	108.950
		WC004	0.451	3.067	17.006	53.168	70.174
	Spring	WC002	0.821	1.100	273.987	212.003	485.990
		WC003	0.420	0.667	64.844	30.423	95.267
		WC004	0.402	2.167	30.193	34.070	64.264
Orthophosphate							
2021	Summer	WC002	0.040	0.050	23.298	13.001	36.299
		WC003	0.051	0.050	16.084	2.460	18.544
		WC004	0.065	0.050	8.898	0.843	9.742
	Fall	WC002	0.037	0.050	13.882	24.167	38.049
		WC003	0.050	0.050	6.002	2.697	8.699
		WC004	0.031	0.050	0.860	0.995	1.856
2022	Winter	WC002	0.029	0.050	5.910	12.896	18.806
		WC003	0.024	0.050	2.230	2.834	5.064
		WC004	0.025	0.037	0.955	0.636	1.591
	Spring	WC002	0.032	0.027	10.785	5.139	15.925
		WC003	0.034	0.050	5.291	2.282	7.573
		WC004	0.024	0.050	1.804	0.786	2.591
TKN							
2021	Summer	WC002	0.983	0.500	577.640	130.012	707.651
		WC003	1.028	0.500	323.127	24.605	347.732
		WC004	0.676	0.567	93.153	9.559	102.712
	Fall	WC002	0.700	0.600	265.222	290.003	555.225
		WC003	0.736	0.600	88.375	32.359	120.734
		WC004	0.894	0.667	25.109	13.270	38.379
2022	Winter	WC002	0.826	0.600	166.381	154.755	321.135
		WC003	0.810	0.633	75.766	35.902	111.669
		WC004	0.961	0.700	36.226	12.136	48.362
	Spring	WC002	1.025	0.700	341.988	134.911	476.899
		WC003	1.157	0.700	178.566	31.944	210.510
		WC004	1.284	1.067	96.510	16.773	113.283

Table E-1. (Continued)

Sample Year	Season	Station	Storm EMC (mg/L)	Baseflow MC (mg/L)	Seasonal Storm Load (lbs)	Seasonal Baseflow Load (lbs)	Seasonal Total Load (lbs)
Total Phosphorous							
2021	Summer	WC002	0.149	0.023	87.860	6.067	93.927
		WC003	0.092	0.020	28.858	0.984	29.842
		WC004	0.051	0.020	7.073	0.337	7.411
	Fall	WC002	0.040	0.037	15.158	17.722	32.881
		WC003	0.054	0.040	6.456	2.157	8.613
		WC004	0.039	0.050	1.107	0.995	2.103
2022	Winter	WC002	0.055	0.040	11.079	10.317	21.396
		WC003	0.052	0.027	4.836	1.512	6.347
		WC004	0.052	0.020	1.960	0.347	2.307
	Spring	WC002	0.088	0.047	29.261	8.994	38.255
		WC003	0.081	0.020	12.448	0.913	13.361
		WC004	0.075	0.107	5.661	1.677	7.338
TSS							
2021	Summer	WC002	38.110	4.000	22,403.187	1,040.093	23,443.280
		WC003	17.559	11.667	5,517.974	574.113	6,092.088
		WC004	10.863	2.667	1,497.156	44.983	1,542.139
	Fall	WC002	10.672	4.000	4,042.448	1,933.353	5,975.800
		WC003	15.814	2.667	1,898.488	143.818	2,042.306
		WC004	6.172	2.667	173.249	53.079	226.328
2022	Winter	WC002	11.259	5.667	2,268.944	1,461.574	3,730.518
		WC003	12.288	5.000	1,149.560	283.440	1,433.000
		WC004	8.681	5.000	327.093	86.687	413.779
	Spring	WC002	13.215	3.667	4,409.907	706.676	5,116.583
		WC003	8.706	2.667	1,344.139	121.692	1,465.831
		WC004	9.922	3.333	745.524	52.416	797.940

Table E-1. (Continued)

Sample Year	Season	Station	Storm EMC (µg/L)	Baseflow MC (µg/L)	Seasonal Storm Load (lbs)	Seasonal Baseflow Load (lbs)	Seasonal Total Load (lbs)
Copper							
2021	Summer	WC002	9.742	0.500	5.727	0.130	5.857
		WC003	2.843	0.633	0.893	0.031	0.925
		WC004	7.020	0.767	0.968	0.013	0.980
	Fall	WC002	4.669	0.200	1.768	0.097	1.865
		WC003	5.087	0.300	0.611	0.016	0.627
		WC004	4.945	1.333	0.139	0.027	0.165
2022	Winter	WC002	5.424	0.333	1.093	0.086	1.179
		WC003	4.217	1.000	0.394	0.057	0.451
		WC004	4.128	1.333	0.156	0.023	0.179
	Spring	WC002	5.144	-	1.717	-	1.717
		WC003	5.878	1.000	0.907	0.046	0.953
		WC004	5.817	0.667	0.437	0.010	0.448
Lead							
2021	Summer	WC002	2.191	0.693	1.288	0.180	1.468
		WC003	0.330	0.400	0.104	0.020	0.123
		WC004	1.046	0.693	0.144	0.012	0.156
	Fall	WC002	0.767	0.687	0.290	0.332	0.622
		WC003	0.771	0.697	0.093	0.038	0.130
		WC004	0.658	0.567	0.018	0.011	0.030
2022	Winter	WC002	0.736	0.767	0.148	0.198	0.346
		WC003	0.591	0.767	0.055	0.043	0.099
		WC004	0.575	1.000	0.022	0.017	0.039
	Spring	WC002	0.674	1.000	0.225	0.193	0.417
		WC003	0.824	1.000	0.127	0.046	0.173
		WC004	0.686	0.800	0.052	0.013	0.064
Zinc							
2021	Summer	WC002	24.290	5.667	14.279	1.473	15.753
		WC003	7.787	6.333	2.447	0.312	2.759
		WC004	17.889	11.667	2.466	0.197	2.662
	Fall	WC002	15.669	10.000	5.936	4.833	10.769
		WC003	24.552	11.000	2.947	0.593	3.541
		WC004	23.665	21.000	0.664	0.418	1.082
2022	Winter	WC002	26.958	13.667	5.433	3.525	8.958
		WC003	24.950	15.000	2.334	0.850	3.184
		WC004	37.010	29.000	1.394	0.503	1.897
	Spring	WC002	16.303	10.667	5.441	2.056	7.496
		WC003	18.796	8.667	2.902	0.395	3.298
		WC004	24.842	19.333	1.867	0.304	2.171

"-" = Not Detected

Wheel Creek

Year 14 – 2022 Biological and Physical Habitat Monitoring Results

December | 2022

Prepared For

Harford County

Watershed Protection and Restoration

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CONTENTS

TABLES

FIGURES

APPENDICES

1. Background

Harford County commissioned a Small Watershed Action Plan for a small subwatershed in the Bush River watershed. The Wheel Creek Small Watershed Action Plan (BayLand, 2008) was completed in August of 2008. Projects identified in the plan were submitted by the County for funding by the Chesapeake and Atlantic Coastal Bays Trust Fund (Trust Fund). Wheel Creek was one of the first project areas selected for funding for restoration by the Trust Fund. In 2009, the County began intensive monitoring of water quality, geomorphology, and ecological condition in the Wheel Creek watershed as projects were implemented. The first restoration project was completed during 2012, and the last projects were completed in July of 2017.

Wheel Creek is an unnamed tributary to Winters Run at Atkisson Reservoir, south of Bel Air, MD. It is a small subwatershed, approximately 393 acres in size (Becker, 2010). Land use in Wheel Creek watershed is dominated by urban development at 46.1% with forest at 34.7% and agriculture at 19.0%. Impervious surfaces in the watershed cover 21.4% of the watershed area. Harford County Public Schools owns the only parcel of substantial forest, on the Harford Glen property.

Maryland Department of Natural Resources' (MD DNR) Maryland Biological Stream Survey (MBSS) monitored seven sites in Wheel Creek and one additional local urban reference site as part of this effort. The MBSS was responsible for the collection and analysis of the data from 2009 to 2018. All sites were sampled through 2017. The four upstream most sites were discontinued prior to the 2018 sampling year. Sampling at the remaining three downstream Wheel Creek sites and the urban control site was continued by MD DNR through 2019. Sampling and data collection at these four sites has continued through 2022.

KCI Technologies, Inc. completed the fourteenth year of chemical, physical, and biological stream sampling in spring and summer of 2022 at the four remaining stream sites in Wheel Creek. This technical memorandum describes the methods and results of the 2022 sampling effort conducted at those sites.

The primary goal of this effort is to characterize baseline stream conditions (biological, physical habitat, and *in situ* chemical) prior to additional restoration project/BMP implementation. A secondary goal is to conduct monitoring in Wheel Creel that can be used to document ecological uplift and habitat improvement as projects are completed within this watershed.

2. Methods

The monitoring effort includes chemical (*in situ* water quality), physical (habitat assessment), and biological (benthic macroinvertebrate, fish, herpetofauna, freshwater mussels, and crayfish) assessments conducted at each of the four active stream sites. The sampling methods used are consistent with MD DNR's MBSS. The methods have been developed locally and are calibrated specifically to Maryland's ecophysiographic regions and stream types.

2.1 Sampling Sites

Four sampling sites were selected within the Wheel Creek watershed (Figure 1) to characterize baseline stream conditions and to assess the effect of planned restoration on the ecological health of the watershed. A brief description of sites follows;

2.1.1 ATKI-101-X

The lowest downstream site in Wheel Creek is ATKI-101-X and it is located near the USGS gage on Wheel Creek. This site has been monitored continuously since 2009 by MBSS until 2019 and by KCI through 2022. The land use upstream of ATKI-101-X is mostly urban (46.1%) with the remaining portion in forest (34.7%) and agriculture (19.0%).

2.1.2 ATKI-102-X

ATKI-102-X is located on the furthest reach downstream, of the west branch of Wheel Creek, a short distance upstream of Wheel Road. The catchment upstream of this site is mostly urban (65.7%) with the remaining land classified as agriculture (18.6%) and forest (15.7%).

2.1.3 ATKI-003-X

ATKI-003-X is located on the furthest downstream site, of the east branch. Nearby, ATKI-102-X is a short distance upstream of Wheel Road. The upstream catchment to this site is mostly urban (57.5%) with the remaining land classified as forest (27.8%) and agriculture (14.1%).

2.1.4 LWIN-108-X

An urban control site is located nearby on an unnamed tributary to Winters Run, downstream of the Atkinson Reservoir. This site was first sampled in 2009 and was continuously monitored by MBSS until 2019 and by KCI from 2020 through 2022. The land use upstream of this site is mostly urban (50.5%) with the remaining portion in agriculture (26.1%) and forest (23.4%).

2.2 Water Quality

Water quality conditions were measured *in situ* during the summer 2022 sampling visits at all Wheel Creek sites. Currently, the MBSS does not measure *in situ* water quality at sites but did so in the past. *In situ* water quality methods used were consistent with those published in DNR, 2010. Field measured parameters include stream water temperature, dissolved oxygen, pH, specific conductance, and turbidity. Measurements at each site were made at the upstream end of the 75-meter sampling reach. *In situ* measurements were made before any sampling activities started to avoid sampling water disturbed by other activities. Most *in situ* parameters (i.e., stream temperature, pH, specific conductivity, and dissolved oxygen) were measured using a multiparameter sonde (YSI Professional Plus), while turbidity was measured with a Hach 2100 Turbidimeter. Water quality meters are regularly inspected and maintained and were calibrated immediately prior to sampling to ensure proper usage and accuracy of the readings.

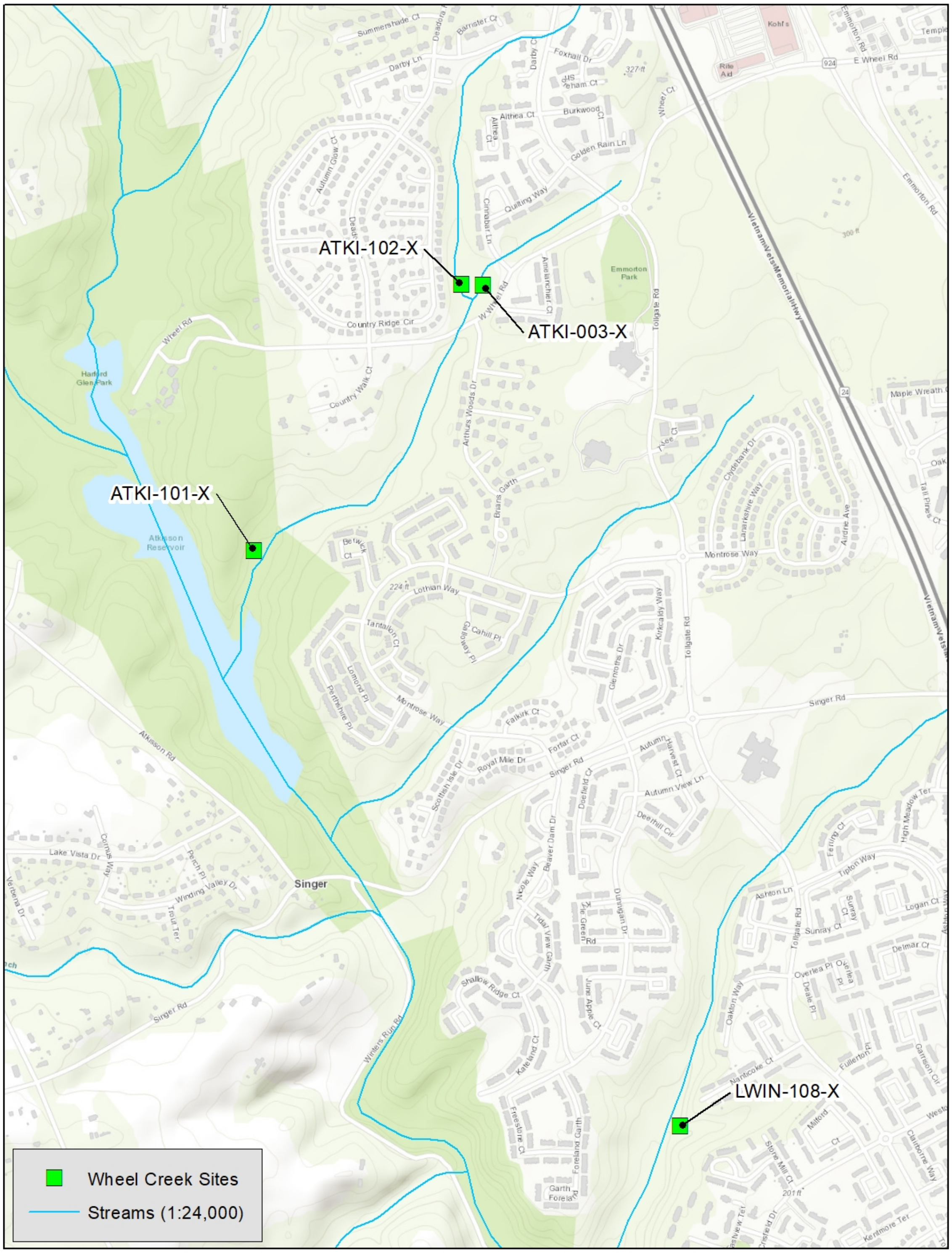

Figure 1 – Location of Sampling Sites

2.3 Physical Habitat Assessment

Each stream site was characterized based on visual observations of physical characteristics and various habitat parameters. The MBSS Physical Habitat Index (PHI; Paul et al. 2002) was used to assess the physical habitat at the site. Most of the habitat parameters were collected during the summer visits, on June 28, July 6, and August 10, 2022.

To reduce individual sampler bias, assessments were completed as a team with discussion and agreement of the scoring for each parameter among field staff certified in MBSS habitat assessment. In addition to the visual assessments, photographs were taken from three locations within each sampling reach (downstream end, midpoint, and upstream end) facing in the upstream and downstream direction, for a total of six (6) photographs per site.

The PHI incorporates the results of a series of habitat parameters selected for Coastal Plain, Piedmont, and Highlands regions. While all parameters are rated during the field assessment, the Piedmont parameters were used to develop the PHI score for these sites because the Wheel Creek watershed is located in Maryland's Piedmont ecophysiographic region. In developing the PHI, MBSS identified eight parameters that have the most discriminatory power for the Piedmont streams. These parameters are used in calculating the PHI (Table 1). Several of the parameters have been found to be drainage area dependent and are scaled accordingly. The drainage area to each site was calculated in GIS by MBSS. The Year 14 analysis will utilize the same catchments for each site to remain consistent with MBSS.

Table 1 – PHI Piedmont Parameters

Piedmont Stream Parameters	
Instream Habitat	Epifaunal Substrate
Bank Stability	Percent Shading
Remoteness	Number Woody Debris/Root wads
Embeddedness	Riffle Quality

Each habitat parameter is given an assessment score ranging from 0-20, with the exception of shading (percentage 0-100%) and woody debris and root wads (total count). A prepared score and scaled score (0-100) are then calculated. The average of these scores yields the final PHI score. The final scores are then ranked according to the ranges shown in Table 2 and assigned corresponding narrative ratings, which allows for a score that can be compared to habitat assessments performed statewide.

Table 2 – PHI Score and Ratings

PHI Score	Narrative Rating
81.0 – 100.0	Minimally Degraded
66.0 – 80.9	Partially Degraded
51.0 – 65.9	Degraded
0.0 – 50.9	Severely Degraded

2.4 Benthic Macroinvertebrate Community Assessment

Benthic macroinvertebrate collection strictly followed MBSS procedures (Stranko et al. 2019). Sampling occurred during the Spring Index Period (March 1 – April 30), samples were collected from all four Wheel Creek sites on March 30, 2022. The monitoring sites consist of a 75-meter reach and benthic macroinvertebrate sampling is conducted once per year. The sampling methods utilize semi-quantitative field collections of the benthic macroinvertebrate community. The multi-habitat D-frame net approach is used to sample a range of the most productive habitat types present within the reach. Best available habitats include riffles, stable woody debris, root wads, root mats, leaf packs, aquatic macrophytes, and undercut banks. In this sampling approach, a total of twenty kicks or jabs (each approximately one square foot) are distributed proportionally among all best available habitats within the stream site and combined into a single composite sample and preserved in 95 percent ethanol. The composite sample contains material collected from approximately 20 square feet of habitat.

2.4.1 Benthic Macroinvertebrate Sample Processing and Laboratory Identification

Benthic macroinvertebrate samples were processed and subsampled according to methods described in the MBSS Laboratory Methods for Benthic Macroinvertebrate Processing and Taxonomy (Boward and Friedman 2019). Subsampling was conducted to standardize the sample size and reduce variation caused by samples of different size. In this method, the sample was spread evenly across a numbered, gridded tray (100 total grids), and a grid was picked at random and picked clean of organisms. If the organism count was 100 or more, then the subsampling was complete. If the organism count was less than 100, then another grid was selected at random and picked clean of organisms. This repeated until the organism count reached 100 to 120 organisms. The 100 (plus 20 percent) organism target is used to allow for specimens that are missing parts or are not mature enough for proper identification, are terrestrial, or meiofauna. Identification of the subsampled specimens was conducted by Cole Ecological, Inc. Taxa were identified to the genus level for most organisms. Groups including Oligochaeta and Nematomorpha were identified to the family level while Nematoda was left at phylum. Individuals of early instars or those that were damaged were identified to the lowest possible level, which could be phylum or order, but in most cases was family. Chironomidae could be further subsampled depending on the number of individuals in the sample and the numbers in each subfamily or tribe. Most taxa were identified using a stereoscope. Temporary slide mounts viewed with a compound microscope were used to identify Oligochaeta to family and for Chironomid sorting to subfamily and tribe. Permanent slide mounts were then used for Chironomid genus level identification. Results were logged on a bench sheet and entered into a spreadsheet for analysis.

2.4.2 Benthic Macroinvertebrate Data Analysis

Benthic macroinvertebrate data were analyzed by KCI using methods developed by MBSS as outlined in the *New Biological Indicators to Better Assess the Condition of Maryland Streams* (Southerland et al. 2005). The Benthic Index of Biotic Integrity (BIBI) approach involves statistical analysis using metrics that have a predictable response to water quality and/or habitat impairment. The metrics selected fall into five major groups including taxa richness, composition measures, tolerance to perturbation, trophic classification, and habit measures. Raw values from each metric were given a score of 1, 3 or 5 based on ranges of values developed for each metric. The results were combined into a scaled IBI score from 1.00 to 5.00, and a corresponding narrative biological condition rating was applied.

Three sets of metric calculations have been developed for Maryland streams based on broad eco-physiographic regions. These include the Coastal Plain, Piedmont, and combined Highlands. The study area is located in the Piedmont region; therefore, the following metrics (Table 3) and IBI scoring (Table 4) were used for the analysis.

Table 3 – Benthic Macroinvertebrate Metric Scoring for the Piedmont BIBI

Metric	Score		
	5	3	1
Total Number of Taxa	≥ 25	24 – 15	< 15
Number of EPT Taxa	≥ 11	5 – 10	< 5
Number of Ephemeroptera Taxa	≥ 4	3 – 2	< 2
% Intolerant to Urban	≥ 51	<51 – 12	< 12
% Chironomidae	≤ 24	>24 – 63	> 63
% Clingers	≥ 74	<74 – 31	< 31

Table 4 – BIBI Condition Ratings

IBI Score	Narrative Rating
4.00 – 5.00	Good
3.00 – 3.99	Fair
2.00 – 2.99	Poor
1.00 – 1.99	Very Poor

2.5 Fish Community Assessment

The fish community at each of the four Wheel Creek sites was sampled during the Summer Index Period, June 1 through September 30, according to methods described in *Maryland Biological Stream Survey: Round Four Field Sampling Manual* (Stranko et al. 2019). These data were collected at the four Wheel Creek sites on June 28, July 6, and August 10, 2022. In general, the approach uses two-pass electrofishing of the entire 75-meter study reach. Block nets were placed at the upstream and downstream ends of the reach, as well as at tributaries or outfall channels, to obstruct fish movement into or out of the study reach. Two passes were completed along the reach to ensure the segment was adequately sampled. The time in seconds for each pass was recorded and the level of effort for each pass was similar. Captured fish were identified to species and enumerated following MBSS protocols (Stranko et al. 2019). A total fish biomass for each electrofishing pass was measured. Unusual anomalies such as fin erosion, tumors, etc. were recorded. Photographic vouchers were taken in lieu of physical voucher specimens.

2.5.1 Fish Data Analysis

Fish data for Wheel Creek sites were analyzed using methods developed by MBSS as outlined in the *New Biological Indicators to Better Assess the Condition of Maryland Streams* (Southerland et al. 2005). The IBI approach involves statistical analysis using metrics that have a predictable response to water quality and/or habitat impairment. Raw values from each metric were assigned a score of 1, 3 or 5 based on ranges of values developed for each metric. The results were combined into a scaled FIBI score, ranging from 1.00 to 5.00, and a corresponding narrative rating of 'Good', 'Fair', 'Poor' or 'Very Poor' was applied, again in accordance with standard practice.

Four sets of FIBI metric calculations have been developed for Maryland streams. These include the Coastal Plain, Eastern Piedmont, and warmwater and coldwater Highlands. Wheel Creek is located in the Eastern Piedmont region, therefore, the following metrics listed in Table 5 were used for the FIBI scoring (Table 6) and analysis.

Table 5 – Fish Metric Scoring for the Piedmont FIBI

Metric	Score		
	5	3	1
Abundance per Square Meter	≥ 1.25	<1.25 – 0.25	< 0.25
Number of Benthic species *	≥ 0.26	<0.26 – 0.09	< 0.09
% Tolerant	≤ 45	>45 – 68	> 68
% Generalist, Omnivores, Invertivores	≤ 80	>80 – 99.9	>99.9
Biomass per Square Meter	≥ 8.6	<8.6 – 4	< 4
% Lithophilic Spawners	≥ 61	<61 – 32	< 32

*Adjusted for catchment size

Table 6 – FIBI Condition Ratings

IBI Score	Narrative Rating
4.00 – 5.00	Good
3.00 – 3.99	Fair
2.00 – 2.99	Poor
1.00 – 1.99	Very Poor

2.6 Herpetofauna Survey

Herpetofauna (i.e., reptiles and amphibians) were surveyed at each of the four Wheel Creek sites using methods following MBSS protocols (Stranko et al. 2019). All collected individuals were identified to species level and released. Photographic vouchers were collected if a specimen could not be positively identified in the field.

Herpetofauna data collection occurs primarily to assist MBSS with supplementing their inventory of biodiversity in Maryland's streams. Currently, MBSS has not developed an index of biotic integrity for herpetofauna, and therefore, they were not used to evaluate the biological integrity of sampling sites throughout this study. Rather, the data are provided to help document existing conditions.

2.7 Freshwater Mussel Survey

A survey of freshwater mussels was conducted at each site using MBSS protocols (Stranko et al. 2019). A search for freshwater mussels was conducted at each site. Any live individuals encountered were identified, photographed, and then returned back to the stream as closely as possible to where they were collected. Any dead shells were retained as voucher specimens.

2.8 Crayfish Survey

Crayfish were surveyed for at each site using MBSS protocols (Stranko et al. 2019). All crayfish observed while electrofishing were captured and retained until the end of each electrofishing pass. Captured crayfish were identified to species and counted before release back into the stream, outside of the 75-meter sampling reach. Crayfish encountered outside of the electrofishing effort were identified and noted on the datasheet as an incidental observation. Any crayfish burrows observed in and around the sampling site were excavated and an attempt made to capture the burrowing crayfish.

2.9 Invasive Plant Survey

A survey of invasive plants was performed at each site during the Summer Index Period, following MBSS protocols (Stranko et al. 2019). The common name and relative abundance of invasive plants (i.e., present or extensive) within view of the study reach and within the 5-meter riparian vegetative zone parallel the stream channel were recorded. Invasive plant data collection occurs to assist MBSS with supplementing their inventory of biodiversity. The data are provided to help document existing conditions at each site.

2.10 Quality Assurance and Quality Control

All work was conducted with strict adherence to established quality assurance and quality control procedures. Biological assessment methods have been designed to be consistent and comparable with the methods used by MBSS (Stranko et al. 2019). Field crews receive yearly training in MBSS protocols and certification by DNR to perform habitat assessment, benthic macroinvertebrate sampling, fish sampling, and fish identification procedures. All field forms are checked and signed by the Crew Leader before leaving the site. Digital data entry is also checked for accuracy. Field equipment are checked regularly and calibrated as necessary prior to use. Calculation of metric scores and IBIs are completed using KCI's controlled and verified spreadsheet and each site undergoes a documented quality control check.

3. Results

Biological monitoring and water quality sampling were conducted to assess the conditions in the Wheel Creek watershed. Presented below are the summary results for each monitoring component.

3.1 Water Quality

Water quality measurements were collected during the Summer Index Period sampling visit at each of the four Wheel Creek sites. Table 7 presents the results of the *in situ* water quality measurements.

Table 7 – In Situ Water Quality Measurement Results 2020-2022

Site	Season	Temperature (°C)	Dissolved Oxygen (mg/L)	pH (Units)	Specific Conductance (µS/cm)	Turbidity (NTU)
ATKI-101-X	Summer 2020	19.3	10.01	7.88	452.2	1.82
ATKI-101-X	Summer 2021	16.6	7.87	7.42	468.3	2.55
ATKI-101-X	Summer 2022	22.2	8.61	7.23	269.5	3.97
ATKI-102-X	Summer 2020	19.0	7.88	7.65	480.9	2.38
ATKI-102-X	Summer 2021	16.0	8.68	6.88	525.4	2.77
ATKI-102-X	Summer 2022	20.8	8.07	6.82	445.9	4.32
ATKI-003-X	Summer 2020	23.5	8.31	8.11	502.1	4.35
ATKI-003-X	Summer 2021	18.9	8.93	7.41	525.9	4.10
ATKI-003-X	Summer 2022	21.5	7.16	7.27	498.4	4.41

LWIN-108-X	Summer 2020	19.1	10.51	7.51	394.0	2.58
LWIN-108-X	Summer 2021	17.0	8.46	7.79	419.9	3.52
LWIN-108-X	Summer 2022	22.8	5.23	7.38	310.8	6.19

Shaded cells indicate values exceeding either water quality criteria or published values

MDE has established acceptable water quality standards for each designated Stream Use Classification, which are listed in the *Code of Maryland Regulations (COMAR) 26.08.02.03-.03 - Water Quality*. Wheel Creek is covered in *COMAR* in Sub-Basin 02-13-07: Bush River Area as Use I-P waters. Specific designated uses for Use I-P streams include public water supply, growth and propagation of fish and aquatic life, water supply for industrial and agricultural use, water contact sports, fishing, and leisure activities involving direct water contact.

The acceptable criteria for Use I-P waters are as follows:

- pH - 6.5 to 8.5
- DO - may not be less than 5 mg/l at any time
- Turbidity - maximum of 150 Nephelometric Turbidity Units (NTU's) and maximum monthly average of 50 NTU
- Temperature - maximum of 90°F (32°C) or ambient temperature of the surface water, whichever is greater

In situ water quality measurements for temperature, dissolved oxygen, pH, and turbidity were within COMAR standards for Use I-P streams. Although MDE does not have a water quality standard for specific conductivity, Morgan and others (Morgan et al, 2007; Morgan et al, 2012) have reported critical values for specific conductance in Maryland streams, above which there is a potential for detrimental effects on the stream biological communities. For the benthic macroinvertebrate community that critical value is 247 µS/cm, and for the fish community it is 171 µS/cm. Each of the four Wheel Creek stream sites had specific conductivity values far exceeding the threshold for both benthic macroinvertebrate and fish community impairments for all water quality sampling events during 2022. Specific conductivity measurements from summer of 2022 were the lowest of the three years of sampling completed since MBSS discontinued sampling. Conductivity levels in this watershed are likely influenced by runoff from impervious surfaces (i.e., roads, sidewalks, parking lots, roof tops). Increased stream inorganic ion concentrations (i.e., conductivity) in urban systems typically results from paved surface de-icing, accumulations in storm-water management facilities (Casey et al. 2013), runoff over impervious surfaces, passage through pipes, and exposure to other infrastructure (Cushman 2006). While elevated conductivity may not directly affect stream biota, its constituents (e.g., chloride, metals, and nutrients) may be present at levels that can cause biological impairment.

3.2 Physical Habitat Assessment

The summary results of the PHI habitat assessments for 2020 and 2022 are presented in Table 8. All Wheel Creek sites are exhibiting compromised physical habitat, with PHI ratings ranging from 'Degraded' to 'Partially Degraded' categories. All sites remained in the lowest categories of 'Degraded' or 'Partially Degraded' over the last three years. Both ATKI-003-X and LWIN-108-X improved from 'Degraded' to 'Partially Degraded' between 2020 and 2022. Overall, the relatively low habitat scores observed throughout the watershed are likely due to urbanization effects on the stream channels. Complete physical habitat data for each site are included in Appendix A.

Table 8 – PHI Habitat Assessment Results for 2020-2022

Site	Season/Year	PHI Score	PHI Narrative Rating
ATKI-101-X	Summer 2020	68.5	Partially Degraded
ATKI-101-X	Summer 2021	68.9	Partially Degraded
ATKI-101-X	Summer 2022	72.7	Partially Degraded
ATKI-102-X	Summer 2020	64.1	Degraded
ATKI-102-X	Summer 2021	63.8	Degraded
ATKI-102-X	Summer 2022	60.4	Degraded
ATKI-003-X	Summer 2020	53.1	Degraded
ATKI-003-X	Summer 2021	73.0	Partially Degraded
ATKI-003-X	Summer 2022	66.4	Partially Degraded
LWIN-108-X	Summer 2020	61.9	Degraded
LWIN-108-X	Summer 2021	73.6	Partially Degraded
LWIN-108-X	Summer 2022	73.6	Partially Degraded

3.3 Benthic Macroinvertebrate Community

The results of 2022 benthic macroinvertebrate community assessments are presented in Table 9. For 2022 benthic macroinvertebrate sampling, all Wheel Creek sites had biological condition ratings in the 'Poor' or 'Very Poor' categories, with ATKI-102-X-2022 and LWIN-108-X receiving the lowest scores of 1.67. BIBI scores ranged from 1.67 to 2.33. Individual metrics were low across all sites, apart from one individual metric in the category of Total Number of Taxa, which site ATKI-101-X had a score of '5' and ATKI-102-X, ATKI-003-X, and LWIN-108-X had a score of '3'. Scores for the metrics Number of EPT, Number of Ephemeroptera Taxa, Percent Intolerant, Percent Chironomidae, and Percent Clingers all either scored a '1' or a '3' across sites. The only category with consistently low scores was Percent Intolerant Urban with a score of '1' received at each of the four sites. These low BIBI scores are likely due to a combination of degraded instream habitat and poor water quality. All sites had measured specific conductivity values greater than the published impairment threshold of 247 µS/cm for benthic macroinvertebrates (Morgan et al., 2007). Complete benthic macroinvertebrate data for 2022 at each site are included in Appendix B.

Table 9 – Benthic Index of Biotic Integrity (BIBI) Summary Data – 2022

Metric	ATKI-101-X	ATKI-102-X	ATKI-003-X	LWIN-108-X
Metric Values				
Total Number of Taxa	33	20	23	17
Number of EPT Taxa	6	3	4	5
Number of Ephemeroptera Taxa	2	0	0	0
% Intolerant to Urban	3.36	2.17	0.75	9.40
% Chironomidae	75	38	57.46	81.20

% Clingers	2.52	2.17	58.21	29.06
Metric Scores				
Total Number of Taxa	5	3	3	3
Number of EPT Taxa	3	1	1	3
Number of Ephemeroptera Taxa	3	1	1	1
% Intolerant to Urban	1	1	1	1
% Chironomidae	1	3	3	1
% Clingers	1	1	3	1
BIBI Score	2.33	1.67	2.00	1.67
Narrative Rating	Poor	Very Poor	Poor	Very Poor

A comparison of BIBI scores from 2009 to 2022 is presented in Table 10 and Figure 2. Two of the four sites had BIBI scores that were higher in 2022 than in 2021. With the greatest improvement being seen in ATKI-101-X going from a score of 1.67 to 2.33 (+0.66). LWIN-108-X also experienced an increase in BIBI score from 2021 to 2022 going from a score of 1.33 to 1.67 (+0.34). Whereas ATKI-102-X and ATKI-003-X maintained the same BIBI scores of 1.67 and 2.00 from 2021 to 2022.

Table 10 – BIBI Scores and Narrative Ratings from 2009 through 2022.

Site	Year	BIBI Score	Narrative Rating
ATKI-101-X	Spring 2009	2.67	Poor
ATKI-101-X	Spring 2010	3.00	Fair
ATKI-101-X	Spring 2011	2.33	Poor
ATKI-101-X	Spring 2012	1.33	Very Poor
ATKI-101-X	Spring 2013	2.00	Poor
ATKI-101-X	Spring 2014	1.00	Very Poor
ATKI-101-X	Spring 2015	2.67	Poor
ATKI-101-X	Spring 2016	2.67	Poor
ATKI-101-X	Spring 2017	1.33	Very Poor
ATKI-101-X	Spring 2018	1.67	Very Poor
ATKI-101-X	Spring 2019	1.67	Very Poor
ATKI-101-X	Spring 2020	2.00	Poor
ATKI-101-X	Spring 2021	1.67	Very Poor
ATKI-101-X	Spring 2022	2.33	Poor
ATKI-102-X	Spring 2009	2.00	Poor
ATKI-102-X	Spring 2010	1.67	Very Poor
ATKI-102-X	Spring 2011	1.33	Very Poor
ATKI-102-X	Spring 2012	1.67	Very Poor
ATKI-102-X	Spring 2013	1.67	Very Poor
ATKI-102-X	Spring 2014	2.00	Poor
ATKI-102-X	Spring 2015	2.00	Poor
ATKI-102-X	Spring 2016	2.67	Poor
ATKI-102-X	Spring 2017	1.67	Very Poor
ATKI-102-X	Spring 2018	1.67	Very Poor
ATKI-102-X	Spring 2019	1.00	Very Poor
ATKI-102-X	Spring 2020	2.00	Poor
ATKI-102-X	Spring 2021	1.67	Very Poor
ATKI-102-X	Spring 2022	1.67	Very Poor
ATKI-003-X	Spring 2009	2.00	Poor
ATKI-003-X	Spring 2010	1.67	Very Poor
ATKI-003-X	Spring 2011	1.33	Very Poor
ATKI-003-X	Spring 2012	2.67	Poor
ATKI-003-X	Spring 2013	2.00	Poor
ATKI-003-X	Spring 2014	1.33	Very Poor
ATKI-003-X	Spring 2015	2.33	Poor
ATKI-003-X	Spring 2016	1.33	Very Poor
ATKI-003-X	Spring 2017	1.33	Very Poor
ATKI-003-X	Spring 2018	1.67	Very Poor
ATKI-003-X	Spring 2019	1.33	Very Poor
ATKI-003-X	Spring 2020	1.67	Very Poor
ATKI-003-X	Spring 2021	2.00	Poor
ATKI-003-X	Spring 2022	2.00	Poor
LWIN-108-X	Spring 2009	2.67	Poor
LWIN-108-X	Spring 2010	3.00	Fair
LWIN-108-X	Spring 2011	1.33	Very Poor
LWIN-108-X	Spring 2012	3.00	Fair
LWIN-108-X	Spring 2013	2.67	Poor
LWIN-108-X	Spring 2014	1.67	Very Poor
LWIN-108-X	Spring 2015	2.33	Poor
LWIN-108-X	Spring 2016	3.00	Fair
LWIN-108-X	Spring 2017	2.00	Poor
LWIN-108-X	Spring 2018	1.33	Very Poor
LWIN-108-X	Spring 2019	1.33	Very Poor
LWIN-108-X	Spring 2020	1.67	Very Poor
LWIN-108-X	Spring 2021	1.33	Very Poor
LWIN-108-X	Spring 2022	1.67	Very Poor

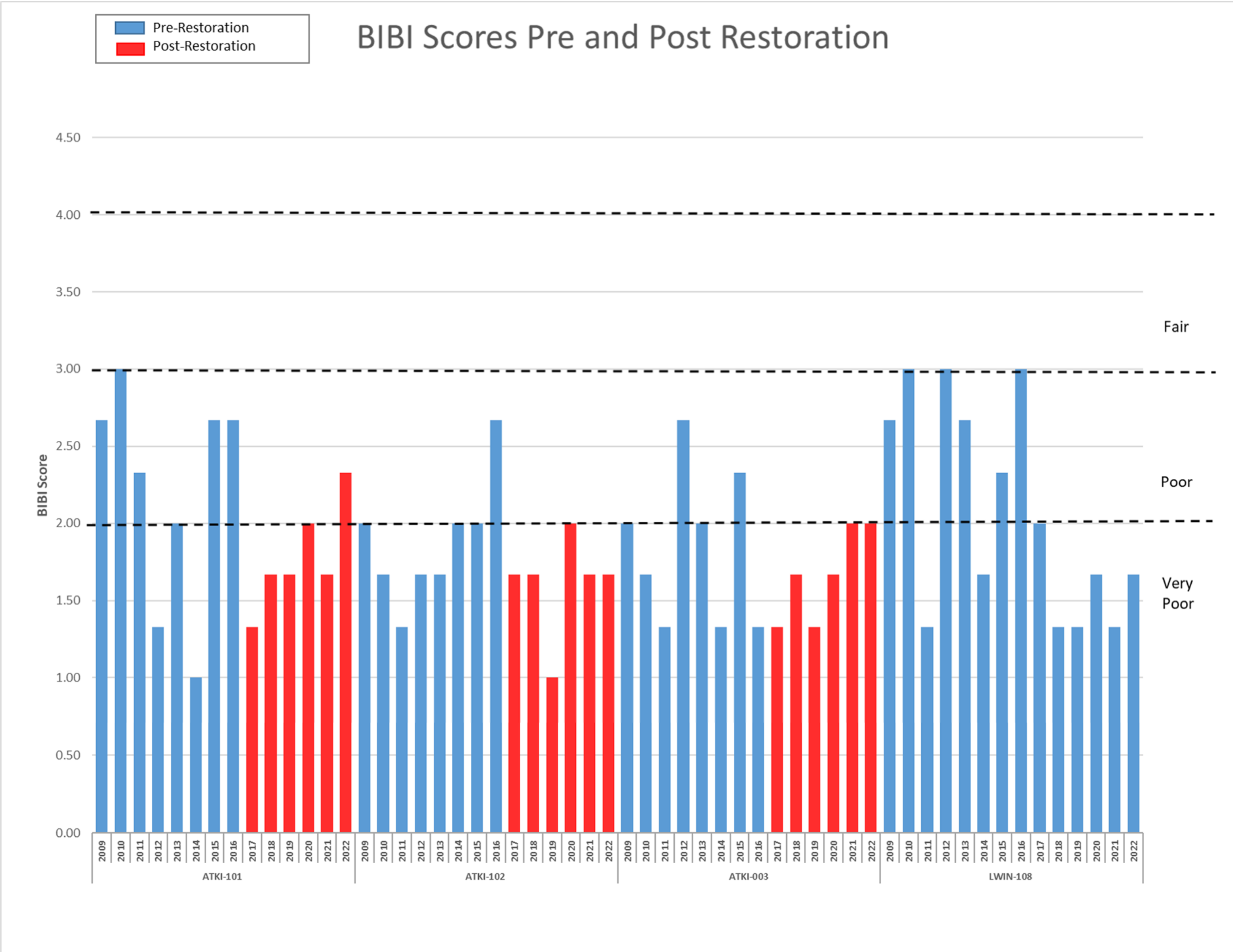

Figure 2 – Wheel Creek BIBI Scores by Year

3.4 Fish Community

The results of the 2022 fish community assessments are presented in Table 11 and a cumulative list of species collected at each site (2020 – 2022) can be found in Table 12. Complete fish community data from 2022 for each site are included in Appendix C.

Table 11 – Fish Index of Biotic Integrity (FIBI) Summary Data – 2022

Metric	ATKI-101-X	ATKI-102-X	ATKI-003-X	LWIN-108-X
Metric Values				
Abundance per Square Meter	3.74	6.11	2.59	1.10
Adjusted Number of Benthic Species	1.13	2.89	6.00	1.10
% Tolerant	48.38	74.64	79.87	44.82
% Generalist, Omnivores, Invertivores	66.16	74.64	79.87	58.86
Biomass per Square Meter	9.42	15.23	8.48	5.77
% Lithophilic Spawners	49.28	48.44	68.90	67.89
Metric Scores				
Abundance per Square Meter	5	5	5	3
Adjusted Number of Benthic Species	5	5	5	5
% Tolerant	3	1	1	5
% Generalist, Omnivores, Invertivores	5	5	5	5
Biomass per Square Meter	5	5	3	3
% Lithophilic Spawners	3	3	5	5
FIBI Score	4.33	4.00	4.00	4.33
Narrative Rating	Good	Good	Good	Good

Table 12 – List of Fish Species Collected at Wheel Creek Sites – 2020-2022

Common Name	Scientific Name	ATKI-101-X	ATKI-102-X	ATKI-003-X	LWIN-108-X
American Eel	*Anguilla rostrata*				X
Margined Madtom	*Noturus insignis*				X
White Sucker	*Catostomus commersonii*	X	X	X	X
Northern Hogsucker	*Hypentelium nigricans*				X
Goldfish	*Carassius auratus*			X	
Rosyside Dace	*Clinostomus funduloides*	X			X
Satinfin Shiner	*Cyprinella analostana*	X			X
Cutlip Minnow	*Exoglossum maxillingua*	X			
Common Shiner	*Luxilus cornutus*	X			X
Golden Shiner	*Notemigonus crysoleucas*	X			
Swallowtail Shiner	*Notropis procne*	X			
Bluntnose Minnow	*Pimephales notatus*	X			X
Fathead Minnow	*Pimephales promelas*	X			
Blacknose Dace	*Rhinichthys atratulus*	X	X	X	X
Longnose Dace	*Rhinichthys cataractae*	X			X
Creek Chub	*Semotilus atromaculatus*	X	X	X	X
Fallfish	*Semotilus corporalis*	X			X
Eastern Mosquitofish	*Gambusia holbrooki*	X			
Banded Killifish	*Fundulus diaphanus*	X			
Blue Ridge Sculpin	*Cottus caeruleomentum*	X	X	X	X
Tessellated Darter	*Etheostoma olmstedi*	X			
Smallmouth Bass	*Micropterus dolomieu*	X			
Largemouth Bass	*Micropterus salmoides*	X			

Common Name	Scientific Name	ATKI-101-X	ATKI-102-X	ATKI-003-X	LWIN-108-X
Redbreast Sunfish	*Lepomis auritus*	X			X
Green Sunfish	*Lepomis cyanellus*	X			
Pumpkinseed	*Lepomis gibbosus*	X			
Bluegill	*Lepomis macrochirus*	X			

The Wheel Creek sites had FIBI ratings ranging from 'Fair' to 'Good' in all monitoring years. Both sites LWIN-108-X and ATKI-101-X had the highest FIBI scores in 2022, 4.33 which are rated as 'Good'. ATKI-102-X and ATKI-003-X were rated as 'Good' with a score of 4.00. ATKI-101-X had the highest diversity of the four sites, with nineteen species of fish, followed by LWIN-108-X, with eight species of fish. ATKI-003-X had four species and ATKI-102-X had three species captured in 2022. Metrics for Adjusted Number of Benthic Species was consistent between the four sites. Percent tolerant varied the most between the sites, with LWIN-108-X scoring a '5', ATKI-101-X scoring a '3', and ATKI-102-X and ATKI-003-X scoring a '1'. Minor differences in the other three metrics between sites accounted for the minor variability in FIBI scores between sites.

A comparison of FIBI scores from 2009 to 2019 during the MBSS years of monitoring as well as 2020, 2021 and 2022, is presented in Table 13 and Figure 3. All four sites had FIBI narrative scores that were the same as or higher in 2022 than in the previous six years of monitoring. ATKI-102-X experienced an increase from 3.67 to 4.00 for the first time since 2017. Though ATKI-101-X and LWIN-108-X decreased in their FIBI scores from 2021 to 2022 by 0.34 they both remained in the narrative rating of 'Good'.

Table 13 – FIBI Scores and Narrative Ratings from 2009 through 2022.

Site	Year	FIBI Score	Narrative Rating
ATKI-101-X	Summer 2009	4.67	Good
ATKI-101-X	Summer 2010	4.33	Good
ATKI-101-X	Summer 2011	4.33	Good
ATKI-101-X	Summer 2012	4.00	Good
ATKI-101-X	Summer 2013	4.67	Good
ATKI-101-X	Summer 2014	4.00	Good
ATKI-101-X	Summer 2015	3.33	Fair
ATKI-101-X	Summer 2016	4.33	Good
ATKI-101-X	Summer 2017	3.67	Fair
ATKI-101-X	Summer 2018	3.00	Fair
ATKI-101-X	Summer 2019	3.67	Fair
ATKI-101-X	Summer 2020	4.00	Good
ATKI-101-X	Summer 2021	4.67	Good
ATKI-101-X	Summer 2022	4.33	Good
ATKI-102-X	Summer 2009	5.00	Good
ATKI-102-X	Summer 2010	4.67	Good
ATKI-102-X	Summer 2011	4.33	Good
ATKI-102-X	Summer 2012	4.67	Good
ATKI-102-X	Summer 2013	4.67	Good
ATKI-102-X	Summer 2014	4.00	Good
ATKI-102-X	Summer 2015	3.67	Fair
ATKI-102-X	Summer 2016	3.33	Fair
ATKI-102-X	Summer 2017	3.67	Fair
ATKI-102-X	Summer 2018	3.67	Fair
ATKI-102-X	Summer 2019	3.67	Fair
ATKI-102-X	Summer 2020	3.67	Fair
ATKI-102-X	Summer 2021	3.67	Fair
ATKI-102-X	Summer 2022	4.00	Good
ATKI-003-X	Summer 2009	4.00	Good
ATKI-003-X	Summer 2010	3.67	Fair
ATKI-003-X	Summer 2011	3.67	Fair
ATKI-003-X	Summer 2012	3.00	Fair
ATKI-003-X	Summer 2013	3.67	Fair
ATKI-003-X	Summer 2014	3.00	Fair
ATKI-003-X	Summer 2015	2.67	Poor
ATKI-003-X	Summer 2016	3.67	Fair
ATKI-003-X	Summer 2017	2.33	Poor
ATKI-003-X	Summer 2018	3.33	Fair
ATKI-003-X	Summer 2019	3.33	Fair
ATKI-003-X	Summer 2020	3.67	Fair
ATKI-003-X	Summer 2021	4.00	Good
ATKI-003-X	Summer 2022	4.00	Good
LWIN-108-X	Summer 2009	4.67	Good
LWIN-108-X	Summer 2010	4.33	Good
LWIN-108-X	Summer 2011	4.33	Good
LWIN-108-X	Summer 2012	4.33	Good
LWIN-108-X	Summer 2013	4.67	Good
LWIN-108-X	Summer 2014	4.33	Good
LWIN-108-X	Summer 2015	4.33	Good
LWIN-108-X	Summer 2016	4.33	Good
LWIN-108-X	Summer 2017	4.67	Good
LWIN-108-X	Summer 2018	4.00	Good
LWIN-108-X	Summer 2019	4.33	Good
LWIN-108-X	Summer 2020	4.33	Good
LWIN-108-X	Summer 2021	4.67	Good
LWIN-108-X	Summer 2022	4.33	Good

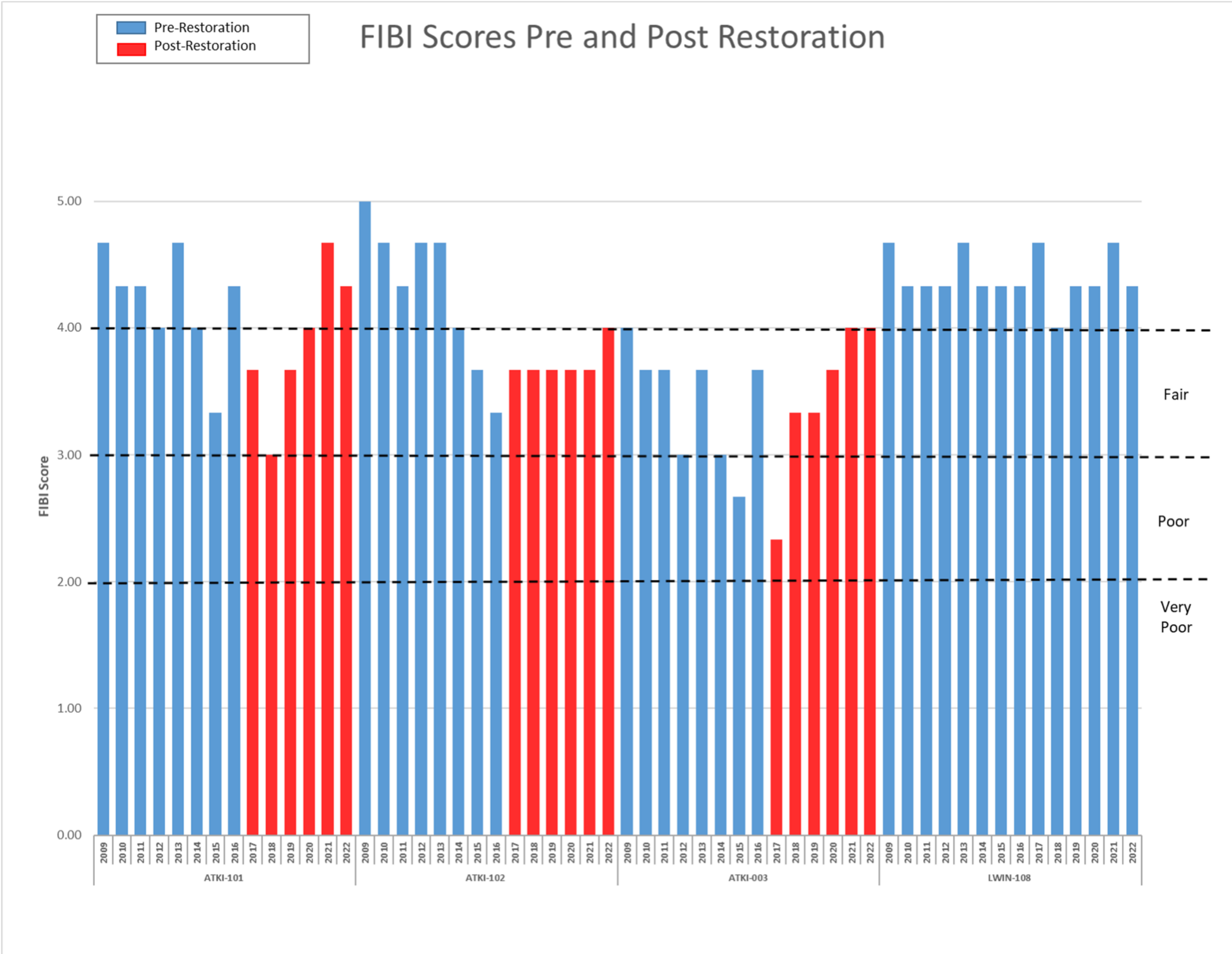

Figure 3 – Wheel Creek FIBI Scores by Year

3.5 Herpetofauna

At least two reptile or amphibian species were observed at each of the sites, as presented in Table 14, which presents all species found at each monitoring site across all sampling visits. ATKI-003-X had the highest diversity with three species found at the site. The most widely distributed species was the Northern Watersnake and Northern Green Frog, which was present at all four Wheel Creek sites. Numbers of stream salamander individuals were low at all sites where they were observed, and consisted entirely of the most pollution-tolerant species the Northern Two-lined Salamander.

Table 14 – Cumulative Herpetofauna Presence at Wheel Creek Sites

Common Name	Scientific Name	ATKI-101-X	ATKI-102-X	ATKI-003-X	LWIN-108-X
American Toad	*Anaxyrus americanus*	X		X	
Northern Green Frog	*Lithobates clamitans melanota*		X	X	
American Bullfrog	*Lithobates catesbeianus*				
Cope's Gray Tree Frog	*Hyla chrysoscelis*			X	
Northern Watersnake	*Nerodia sipedon*	X	X		
Stream Salamanders					
Northern Two-lined Salamander	*Eurycea bislineata*	X	X	X	X

The low density and diversity of stream salamanders at all sites is likely due to a combination of habitat degradation and water quality impairment. There was very little suitable stream salamander habitat present at ATKI-102-X and ATKI-003-X during the first visit for the field crew to search. Stream salamanders generally prefer large cover objects over loose cobble and gravel, creating a moist microclimate and many interstices for shelter and foraging. Water quality may be influencing the distribution of stream salamanders in the Wheel Creek watershed. Measured specific conductivity was high at all four sites, ranging from 269.5 to 498.4 µS/cm. Stream salamanders breathe through their skins, and because of their highly permeable skin, are particularly sensitive to water quality impairments. The high conductivity values suggest that salamanders would experience osmotic difficulties in these conditions.

3.6 Freshwater Mussels

No freshwater mussels were observed at any Wheel Creek site during 2020, 2021, or 2022 field visits. The lack of freshwater mussels at these sites is likely due to a combination of habitat degradation and water quality impairment. Freshwater mussels are relatively sessile organisms which live partially embedded within the stream substrates. The flashy hydrology characteristic of urban streams like Wheel Creek creates habitat conditions unsuitable for freshwater mussels. Also, it is likely that water quality conditions in urban streams are outside the range of tolerance of these sensitive organisms.

3.7 Crayfish

Crayfish were observed at all of the Wheel Creek sites, with the exception of LWIN-108-X in 2022. *Faxonius virilis*, a non-native species, was the only crayfish species observed. Crayfish burrows were not observed at any of the Wheel Creek sites. The lack of native crayfish is most likely due to competition with non-native crayfish. In the Patapsco River watershed, *Faxonius virilis* has displaced the native *Faxonius limosus* from the entire watershed (Kilian et al. 2010). It is likely that similar species displacement has occurred in the Winters Run watershed. Water quality conditions may also be impacting crayfish, but currently, the water quality requirements for crayfish in Maryland are poorly understood.

3.8 Invasive Plant Species

Invasive plant species were present at each of the four Wheel Creek sites. Table 15 presents all invasive species found at each monitoring site across all sampling visits. ATKI-003-X has nine invasive plant species, while ATKI-102-X has seven species, ATKI-101-X has six species, and LWIN-108-X only has two species. Multiflora rose and Japanese stiltgrass were the most widely distributed invasive plant species, found at each of the four sites.

Table 15 – Cumulative Invasive Plant Species Presence at Wheel Creek Sites

Common Name	Scientific Name	ATKI-101-X	ATKI-102-X	ATKI-003-X	LWIN-108-X
Japanese barberry	*Berberis thunbergii*	X	X	X	
Garlic mustard	*Alliaria petiolata*	X		X	
Oriental bittersweet	*Celastrus orbiculatus*	X	X	X	
Japanese stiltgrass	*Microstegium vimineum*	X	X	X	X
Multiflora rose	*Rosa multiflora*	X	X	X	X
Wineberry	*Rubus phoenicolasius*	X		X	
Mile-a-minute	*Persicaria perfoilata*		X	X	
Privet	*Ligustrum sp.*		X	X	
Japanese honeysuckle	*Lonicera japonica*		X	X	

4. Conclusions

Ecological conditions at the three treatment sites in Wheel Creek, as well as the urban control site, vary over time throughout the 14 years of monitoring, with some exhibiting trends towards further degradation. BIBI scores at all four sites have remained in the 'Very Poor' or 'Poor' categories, varying slightly from year to year. While two sites appear to show trends toward lower BIBI scores over time (Figure 4), FIBI scores at the three Wheel Creek treatment sites also vary over time, but generally improved or remained in the 'Good' category. Comparing data between the pre- and post-restoration periods, there is no discernable ecological lift in the IBI scores. The ecological condition of Wheel Creek, especially the benthic macroinvertebrate community, continues in a degraded condition similar to other post-restoration urban streams in central Maryland (Hilderbrand et al 2019; Southerland et al 2018). However, the urban control site is showing a trend towards further degradation of the benthic macroinvertebrate community in recent years, suggesting that recent restoration efforts may be ameliorating effects of urbanization within the watershed. Although, it should be noted that fish communities at the urban control site have consistently been rated as 'Good' throughout the entire monitoring period.

Though there has been little additional development around Wheel Creek the stream itself could be facing urban stream syndrome. Urban stream syndrome can be defined as framework of common responses seen in streams that are in or near urban settings (Booth, Roy et al 2018). Frequent stream responses can include increased nutrient loads and increases dominance of tolerant species (Walsh, Roy et al 2005). Despite restoration efforts some pollutants and nutrients can have legacy effects on a stream causing the stream to remain impaired, ultimately preventing the stream from supporting benthic communities. Lastly, the proximity of Wheel Creek to healthy and biologically diverse communities may not be conducive to dispersal or migration of benthic taxa causing the re-establishment of more sensitive populations to be delayed or non-existent (Southerland et al 2018).

A more comprehensive analysis of data collected at Wheel Creek project sites will occur at the end of 2024. This larger analysis will integrate all ecological, habitat, and water quality data to try to identify correlations in the data set that would help understand what is affecting ecological condition in the Wheel

Creek watershed. Analysis will focus not only on the IBI scores, but on individual metrics and species-level response over time to try and highlight changes, if any exist, in the post-restoration data.

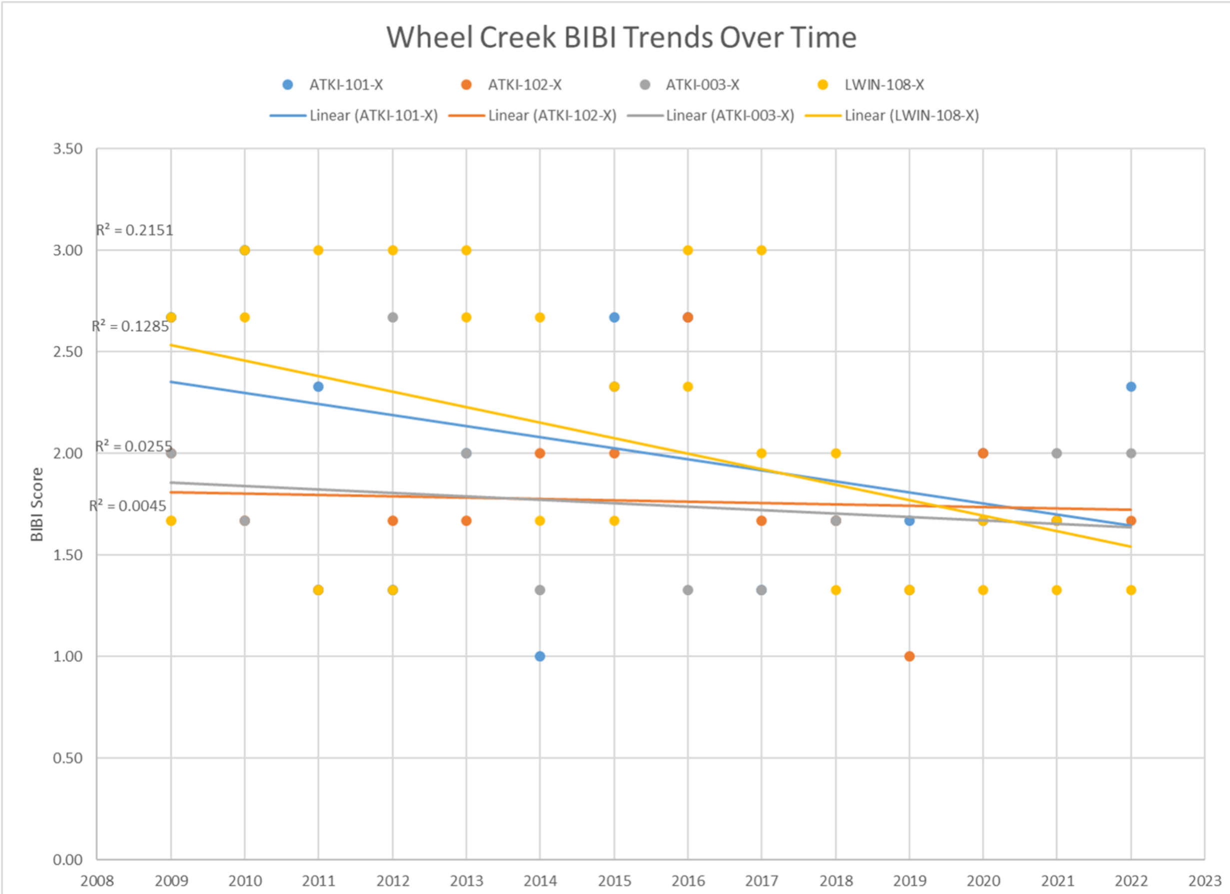

Figure 4 - BIBI Trends over time (2009 - 2022)

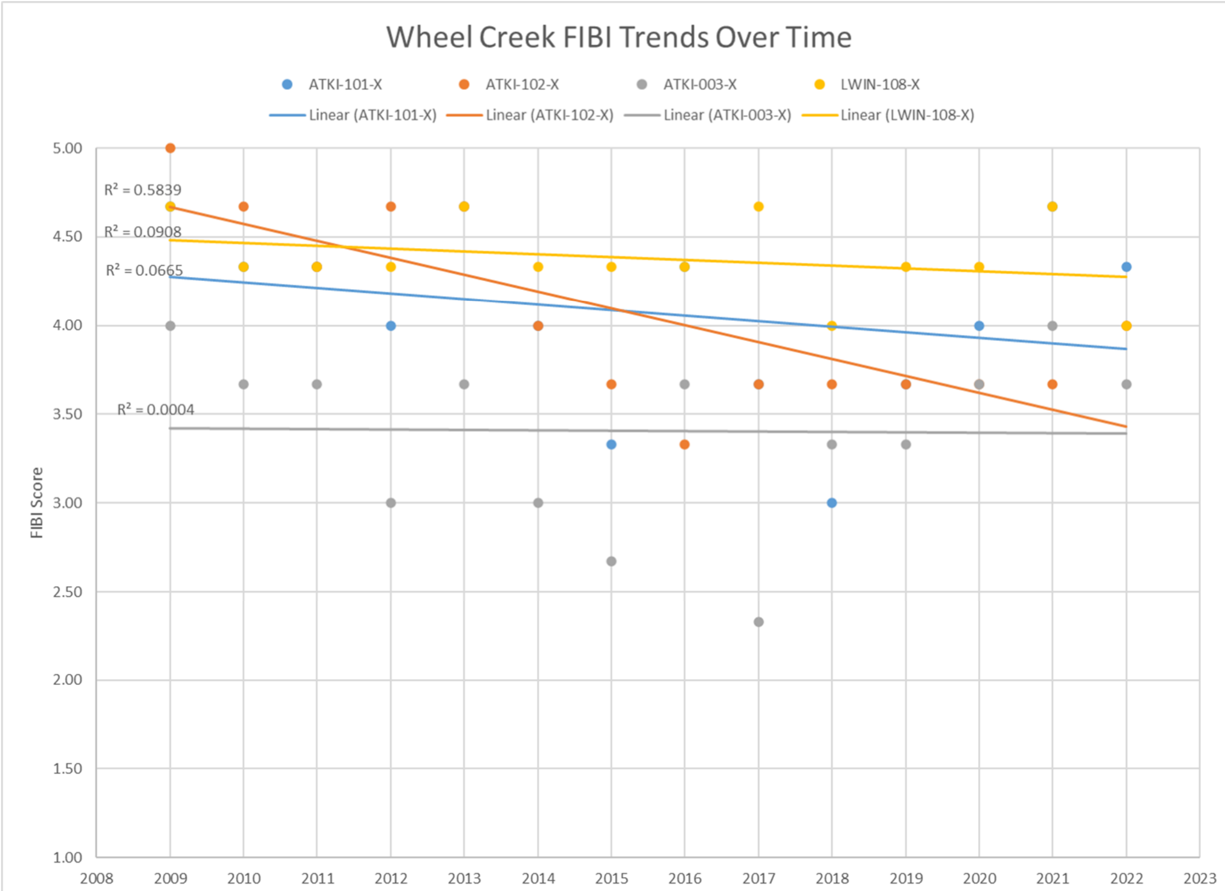

Figure 5 - FIBI Trends over time (2009 - 2022)

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Appendix A: Physical Habitat Data

Project Name:	Wheel Creek Biological Monitoring
Project Number:	161602035.06
Prepared by:	MA
Prepared date:	11/3/2022
Checked by:	AJB
Checked date:	12/2/2022

PHI_Piedmont_v3_WheelCrk_2022.xlsx

KCI TECHNOLOGIES

		RAW DATA								SCALED METRICS								SCORES	
Site	Subshed Area (ac)*	Instream Habitat	Epifaunal Substrate	Embeddedness	Percent Shading	# Woody Debris/ Rootwads	Riffle Quality	Bank Stability	Remoteness Score	Instream Habitat	Epifaunal Substrate	Embeddedness	Percent Shading	# Woody Debris/ Rootwads	Riffle Quality	Bank Stability	Remoteness	PHI	PHI Rating
ATKI-101-X-2022	393.08	15	12	15	80	2	15	19	8	87.66	64.71	94.44	72.07	16.67	97.57	100.00	48.50	72.7	Partially Degraded
ATKI-102-X-2022	146.07	11	8	20	60	2	10	18	7	66.48	41.18	88.89	50.25	16.67	77.37	98.77	43.52	60.4	Degraded
ATKI-003-X-2022	105.03	11	10	35	65	8	11	17	6	67.89	52.94	72.22	51.90	66.67	84.22	97.42	37.82	66.4	Partially Degraded
LWIN-108-X-2022	411.86	14	12	0	85	8	13	8	9	81.11	64.71	100.00	77.06	66.67	87.13	58.00	54.03	73.6	Partially Degraded

Score	Narrative Rating
81-100	Minimally Degraded
66.0-80.9	Partially Degraded
51.0-65.9	Degraded
0-50.9	Severely Degraded

Appendix B: Benthic Macroinvertebrate Data

Project Name:	Wheel Creek Monitoring 2021		
Project Number:	161602035.06		2022_WheelCrk_Piedmont.xlsx
Prepared by:	MA	Checked by: AJB	Version:
Prepared date:	10/5/2022	Checked date: 11/10/2022	

Metric	ATKI-101-X-2022	ATKI-102-X-2022	ATKI-003-X-2022	LWIN-108-X-2022
Raw Scores				
Total Number of Taxa	33	20	23	17
Number of EPT Taxa	6	3	4	5
Number of Ephemeroptera Taxa	2	0	0	0
Percent Intolerant Urban	3.36	2.17	0.75	9.40
Percent Chironomidae	75	38	57.46	81.20
Percent Clingers	2.52	2.17	58.21	29.06
BIBI Scores				
Total Number of Taxa	5	3	3	3
Number of EPT Taxa	3	1	1	3
Number of Ephemeroptera Taxa	3	1	1	1
Percent Intolerant Urban	1	1	1	1
Percent Chironomidae	1	3	3	1
Percent Clingers	1	1	3	1
BIBI Score	***2.33***	***1.67***	***2.00***	***1.67***
Narrative Rating	***Poor***	***Very Poor***	***Poor***	***Very Poor***

Piedmont		Score	
Metric	**5**	**3**	**1**
Total Number of Taxa	≥25	15 - 24	<15
Number of EPT Taxa	≥11	5 - 10	<5
Number Ephemeroptera Taxa	≥4	2 - 3	<2
Percent Intolerant Urban	≥51	< 51 - 12	<12
Percent Chironomidae	≤24	> 24 - 63	>63
Percent Clingers	≥74	< 74 - 31	<31

Project Name: Wheel Creek Monitoring 2021
Project Number: 161602035.06
Prepared by: MA Checked by: AJB
Prepared date: 10/5/2022 Checked date: 11/10/2022

2022_WheelCrk_Piedmont.xlsx
Version: 1
Site Name: -101-X-2022

Subphylum/ Class	Order	Family	Genus	Final ID	Note[1]	# of Org	FFG[2]	Habit[3]	Tolerance Value[4]
Insecta	Ephemeroptera	Baetidae	Acentrella	ACENTRELLA	I	3	Collector	sw, cn	4.9
Insecta	Ephemeroptera	Baetidae	Acerpenna	ACERPENNA	L	1	Collector	sw, cn	2.6
Insecta	Diptera	Tipulidae	Antocha	ANTOCHA	L	1	Collector	cn	8
Insecta	Diptera	Chironomidae	Brillia	BRILLIA	L	1	Shredder	bu, sp	7.4
Insecta	Diptera	Chironomidae	Cardiocladius	CARDIOCLADIUS	L	9	Predator	bu, cn	10
Insecta	Trichoptera	Hydropsychidae	Cheumatopsyche	CHEUMATOPSYCHE	L	3	Filterer	cn	6.5
Insecta	Trichoptera	Philopotamidae	Chimarra	CHIMARRA	L	2	Filterer	cn	4.4
Insecta	Diptera	Empididae	Clinocera	CLINOCERA	L	5	Predator	cn	7.4
Insecta	Diptera	Chironomidae	Corynoneura	CORYNONEURA	L	9	Collector	sp	4.1
Insecta	Diptera	Chironomidae	Cricotopus	CRICOTOPUS	L/P	6	Shredder	cn, bu	9.6
Insecta	Diptera	Chironomidae	Cricotopus/Orthocladi	CRICOTOPUS/ORTHOCLADIUS	I	10	Shredder	0	7.7
Insecta	Diptera	Ceratopogonidae	Dasyhelea	DASYHELEA	L	1	Collector	sp	3.6
Insecta	Diptera	Chironomidae	Diamesa	DIAMESA	L	1	Collector	sp	8.5
Insecta	Trichoptera	Philopotamidae	Dolophilodes	DOLOPHILODES	I	1	Filterer	cn	1.7
Insecta	Diptera	Chironomidae	Eukiefferiella	EUKIEFFERIELLA	L	2	Collector	sp	6.1
Turbellaria	Tricladida	Dugesiidae	Girardia	GIRARDIA	A	1	Predator	sp	9.3
Insecta	Trichoptera	Hydropsychidae	Hydropsyche	HYDROPSYCHE	L	2	Filterer	cn	7.5
Oligochaeta	Haplotaxida	Naididae	not identified	NAIDIDAE	A	1	Collector	bu	8.5
Insecta	Diptera	Empididae	Neoplasta	NEOPLASTA	L	1	Predator	0	na
Insecta	Diptera	Chironomidae	Neozavrelia	NEOZAVRELIA	L	2	0	0	na
Insecta	Diptera	Chironomidae	Orthocladius	ORTHOCLADIUS	L/P	22	Collector	sp, bu	9.2
Insecta	Coleoptera	Elmidae	Oulimnius	OULIMNIUS	L	1	Scraper	cn	2.7
Insecta	Diptera	Chironomidae	Parametriocnemus	PARAMETRIOCNEMUS	L	7	Collector	sp	4.6
Insecta	Diptera	Chironomidae	Polypedilum	POLYPEDILUM	L	9	Shredder	cb, cn	6.3
Insecta	Diptera	Chironomidae	Potthastia	POTTHASTIA	L	1	Collector	sp	0.01
Insecta	Diptera	Chironomidae	Rheocricotopus	RHEOCRICOTOPUS	L	1	Collector	sp	6.2
Insecta	Diptera	Chironomidae	Rheotanytarsus	RHEOTANYTARSUS	L	2	Filterer	cn	7.2
Insecta	Diptera	Simuliidae	Simulium	SIMULIUM	L	5	Filterer	cn	5.7
Insecta	Diptera	Chironomidae	Sympotthastia	SYMPOTTHASTIA	L	2	Collector	sp	8.2
Insecta	Diptera	Chironomidae	Tanytarsus	TANYTARSUS	L	2	Filterer	cb, cn	4.9
Insecta	Diptera	Chironomidae	Thienemanniella	THIENEMANNIELLA	L	1	Collector	sp	5.1
Insecta	Diptera	Chironomidae	Thienemannimyia gro	THIENEMANNIMYIA GROUP	L	1	Predator	sp	8.2
Insecta	Diptera	Tipulidae	Tipula	TIPULA	L	2	Shredder	bu	6.7
Insecta	Diptera	Chironomidae	Tvetenia	TVETENIA	L	1	Collector	sp	5.1

1 Life Stage, I - Immature, P- Pupa, A - Adult, U - Undetermined; 2 Functional Feeding Group; 3 Primary habit or form of locomotion, includes bu - burrower, cn - clinger, cb - climber, sk - skater, sp - sprawler, sw - swimmer; 4 Tolerance Values, based on Hilsenhoff, modified for Maryland. An entry of "0" indicates information for the particular taxa was not available.

Project Name: Wheel Creek Monitoring 2021
Project Number: 161602035.06
Prepared by: MA   Checked by: AJB
Prepared date: 10/5/2022   Checked date: 11/10/2022

2022_WheelCrk_Piedmont.xlsx
Version: 1
Site Name: -102-X-2022

KCI TECHNOLOGIES

Subphylum/ Class	Order	Family	Genus	Final ID	Note[1]	# of Org	FFG[2]	Habit[3]	Tolerance Value[4]
Insecta	Trichoptera	Hydropsychidae	Cheumatopsyche	CHEUMATOPSYCHE	L	2	Filterer	cn	6.5
Insecta	Trichoptera	Philopotamidae	Chimarra	CHIMARRA	L	2	Filterer	cn	4.4
Insecta	Diptera	Chironomidae	Cricotopus	CRICOTOPUS	L	11	Shredder	cn, bu	9.6
Insecta	Diptera	Chironomidae	Cricotopus/Orthocladi	CRICOTOPUS/ORTHOCLADIUS	L	1	Shredder	0	7.7
Insecta	Diptera	Chironomidae	Diamesa	DIAMESA	L	1	Collector	sp	8.5
Insecta	Trichoptera	Hydropsychidae	Hydropsyche	HYDROPSYCHE	L	2	Filterer	cn	7.5
Insecta	Diptera	Chironomidae	Micropsectra	MICROPSECTRA	L	1	Collector	cb, sp	2.1
Oligochaeta	Haplotaxida	Naididae	not identified	NAIDIDAE	A	76	Collector	bu	8.5
Insecta	Diptera	Empididae	Neoplasta	NEOPLASTA	L	1	Predator	0	na
Insecta	Diptera	Chironomidae	Neozavrelia	NEOZAVRELIA	L	2	0	0	na
Insecta	Diptera	Chironomidae	Orthocladius	ORTHOCLADIUS	L/P	16	Collector	sp, bu	9.2
Insecta	Diptera	Chironomidae	Parametriocnemus	PARAMETRIOCNEMUS	L	1	Collector	sp	4.6
Insecta	Diptera	Chironomidae	Polypedilum	POLYPEDILUM	L	5	Shredder	cb, cn	6.3
Insecta	Diptera	Chironomidae	Potthastia	POTTHASTIA	L	2	Collector	sp	0.01
Insecta	Diptera	Chironomidae	Rheocricotopus	RHEOCRICOTOPUS	L	1	Collector	sp	6.2
Insecta	Diptera	Chironomidae	Rheotanytarsus	RHEOTANYTARSUS	L	3	Filterer	cn	7.2
Insecta	Diptera	Simuliidae	Simulium	SIMULIUM	L	2	Filterer	cn	5.7
Insecta	Coleoptera	Elmidae	Stenelmis	STENELMIS	L	1	Scraper	cn	7.1
Insecta	Diptera	Chironomidae	Sympotthastia	SYMPOTTHASTIA	L	2	Collector	sp	8.2
Insecta	Diptera	Chironomidae	Tanytarsus	TANYTARSUS	L	1	Filterer	cb, cn	4.9
Insecta	Diptera	Chironomidae	Tvetenia	TVETENIA	L	5	Collector	sp	5.1

1 Life Stage, I - Immature, P- Pupa, A - Adult, U - Undetermined; 2 Functional Feeding Group; 3 Primary habit or form of locomotion, includes bu - burrower, cn - clinger, cb - climber, sk - skater, sp - sprawler, sw - swimmer; 4 Tolerance Values, based on Hilsenhoff, modified for Maryland. An entry of "0" indicates information for the particular taxa was not available.

Project Name: Wheel Creek Monitoring 2021
Project Number: 161602035.06
Prepared by: MA Checked by: AJB
Prepared date: 10/5/2022 Checked date: 11/10/2022

2022_WheelCrk_Piedmont.xlsx
Version: 1
Site Name: -003-X-2022

KCI TECHNOLOGIES

Subphylum/ Class	Order	Family	Genus	Final ID	Note[1]	# of Org	FFG[2]	Habit[3]	Tolerance Value[4]
Insecta	Plecoptera	Nemouridae	Amphinemura	AMPHINEMURA	L	1	Shredder	sp, cn	3
Insecta	Diptera	Tipulidae	Antocha	ANTOCHA	L	2	Collector	cn	8
Insecta	Trichoptera	Hydropsychidae	Cheumatopsyche	CHEUMATOPSYCHE	L	2	Filterer	cn	6.5
Insecta	Trichoptera	Philopotamidae	Chimarra	CHIMARRA	L	17	Filterer	cn	4.4
Insecta	Diptera	Empididae	Clinocera	CLINOCERA	L	14	Predator	cn	7.4
Insecta	Collembola	not identified	not identified	COLLEMBOLA		1	0	0	6
Insecta	Diptera	Chironomidae	Cricotopus	CRICOTOPUS	L	10	Shredder	cn, bu	9.6
Insecta	Diptera	Chironomidae	Cricotopus/Orthocladi	CRICOTOPUS/ORTHOCLADIUS	I	8	Shredder	0	7.7
Insecta	Diptera	Chironomidae	Diamesa	DIAMESA	L	1	Collector	sp	8.5
Insecta	Diptera	Chironomidae	Eukiefferiella	EUKIEFFERIELLA	L	1	Collector	sp	6.1
Insecta	Trichoptera	Hydropsychidae	Hydropsyche	HYDROPSYCHE	L	3	Filterer	cn	7.5
Insecta	Diptera	Empididae	Neoplasta	NEOPLASTA	L	2	Predator	0	na
Insecta	Diptera	Chironomidae	Neozavrelia	NEOZAVRELIA	L	2	0	0	na
Insecta	Diptera	Chironomidae	Orthocladius	ORTHOCLADIUS	L	8	Collector	sp, bu	9.2
Insecta	Diptera	Chironomidae	Parametriocnemus	PARAMETRIOCNEMUS	L	11	Collector	sp	4.6
Insecta	Diptera	Chironomidae	Polypedilum	POLYPEDILUM	L	3	Shredder	cb, cn	6.3
Insecta	Coleoptera	Psephenidae	Psephenus	PSEPHENUS	L	1	Scraper	cn	4.4
Insecta	Diptera	Chironomidae	Rheotanytarsus	RHEOTANYTARSUS	L/P	5	Filterer	cn	7.2
Insecta	Diptera	Simuliidae	Simulium	SIMULIUM	L	3	Filterer	cn	5.7
Insecta	Coleoptera	Elmidae	Stenelmis	STENELMIS	L	11	Scraper	cn	7.1
Insecta	Diptera	Chironomidae	Tanytarsus	TANYTARSUS	L	6	Filterer	cb, cn	4.9
Insecta	Diptera	Chironomidae	Thienemanniella	THIENEMANNIELLA	L	5	Collector	sp	5.1
Insecta	Diptera	Chironomidae	Thienemannimyia gro	THIENEMANNIMYIA GROUP	L/P	15	Predator	sp	8.2
Insecta	Diptera	Chironomidae	Tvetenia	TVETENIA	L	2	Collector	sp	5.1

1 Life Stage, I - Immature, P- Pupa, A - Adult, U - Undetermined; 2 Functional Feeding Group; 3 Primary habit or form of locomotion, includes bu - burrower, cn - clinger, cb - climber, sk - skater, sp - sprawler, sw - swimmer; 4 Tolerance Values, based on Hilsenhoff, modified for Maryland. An entry of "0" indicates information for the particular taxa was not available.

Project Name: Wheel Creek Monitoring 2021
Project Number: 161602035.06
Prepared by: MA Checked by: AJB
Prepared date: 10/5/2022 Checked date: 11/10/2022

2022_WheelCrk_Piedmont.xlsx
Version: 1
Site Name: -108-X-2022

KCI TECHNOLOGIES

Subphylum/ Class	Order	Family	Genus	Final ID	Note[1]	# of Org	FFG[2]	Habit[3]	Tolerance Value[4]
Insecta	Plecoptera	Nemouridae	Amphinemura	AMPHINEMURA	L	7	Shredder	sp, cn	3
Insecta	Diptera	Chironomidae	Brillia	BRILLIA	L	1	Shredder	bu, sp	7.4
Insecta	Diptera	Chironomidae	Chaetocladius	CHAETOCLADIUS	L	2	Collector	sp	7
Insecta	Trichoptera	Hydropsychidae	Cheumatopsyche	CHEUMATOPSYCHE	L	5	Filterer	cn	6.5
Insecta	Trichoptera	Philopotamidae	Chimarra	CHIMARRA	L	3	Filterer	cn	4.4
Insecta	Diptera	Empididae	Clinocera	CLINOCERA	L	1	Predator	cn	7.4
Insecta	Diptera	Chironomidae	Corynoneura	CORYNONEURA	L	7	Collector	sp	4.1
Insecta	Diptera	Chironomidae	Cricotopus	CRICOTOPUS	L	1	Shredder	cn, bu	9.6
Insecta	Diptera	Chironomidae	Cricotopus/Orthocladius	CRICOTOPUS/ORTHOCLADIUS	I	3	Shredder	0	7.7
Insecta	Trichoptera	Glossosomatidae	not identified	GLOSSOSOMATIDAE	P	1	Scraper	cn	1
Insecta	Trichoptera	Hydropsychidae	Hydropsyche	HYDROPSYCHE	L	1	Filterer	cn	7.5
Insecta	Trichoptera	Hydropsychidae	not identified	HYDROPSYCHIDAE	P	1	Filterer	cn	5.7
Insecta	Diptera	Chironomidae	Orthocladius	ORTHOCLADIUS	L/P	51	Collector	sp, bu	9.2
Insecta	Diptera	Chironomidae	Parametriocnemus	PARAMETRIOCNEMUS	L	4	Collector	sp	4.6
Insecta	Trichoptera	Philopotamidae	not identified	PHILOPOTAMIDAE	I	2	Filterer	cn	2.6
Gastropoda	Basommatophora	Physidae	Physella	PHYSELLA	I	1	Scraper	cb	8
Insecta	Diptera	Chironomidae	Polypedilum	POLYPEDILUM	L	12	Shredder	cb, cn	6.3
Insecta	Diptera	Chironomidae	Potthastia	POTTHASTIA	L	1	Collector	sp	0.01
Insecta	Diptera	Chironomidae	Sympotthastia	SYMPOTTHASTIA	L/P	12	Collector	sp	8.2
Insecta	Diptera	Chironomidae	Thienemanniella	THIENEMANNIELLA	L	1	Collector	sp	5.1

1 Life Stage, I - Immature, P- Pupa, A - Adult, U - Undetermined; 2 Functional Feeding Group; 3 Primary habit or form of locomotion, includes bu - burrower, cn - clinger, cb - climber, sk - skater, sp - sprawler, sw - swimmer; 4 Tolerance Values, based on Hilsenhoff, modified for Maryland. An entry of "0" indicates information for the particular taxa was not available.

Appendix C: Fish Data

Project Name: Wheel Creek Monitoring 2022
Project Number: 161602035.06
Prepared by: SLF
Prepared date: 8/11/2022

Checked by: AJB
Checked date: 11/10/2022

FIBI_WheelCrk_2022.xlsx

KCI TECHNOLOGIES

Metric	ATKI-101-X-2022	ATKI-102-X-2022	ATKI-003-X-2022	LWIN-108-X-2022
Raw Scores				
Abundance per square meter	3.74	6.11	2.59	1.10
Adjusted Number of Benthic species	1.13	2.89	6.00	1.10
% Tolerant	48.38%	74.64%	79.87%	44.82%
% Generalist, Omnivores, Invertivores	66.16%	74.64%	79.87%	58.86%
Biomass per square meter	9.42	15.23	8.48	5.77
% Lithophilic Spawners	49.28%	48.44%	68.90%	67.89%
FIBI Scores				
Abundance per square meter	5	5	5	3
Adjusted Number of Benthic species	5	5	5	5
% Tolerant	3	1	1	5
% Generalist, Omnivores, Invertivores	5	5	5	5
Biomass per square meter	5	5	3	3
% Lithophilic Spawners	3	3	5	5
FIBI Score	***4.33***	***4.00***	***4.00***	***4.33***
Narrative Rating	***Good***	***Good***	***Good***	***Good***

Eastern Piedmont	**Score**		
Metric	**5**	**3**	**1**
Abundance per square meter	≥ 1.25	< 1.25 - 0.25	< 0.25
Adjusted Number of Benthic species	≥ 0.26	< 0.26 - 0.09	< 0.09
% Tolerant	≤ 45	> 45 - 68	> 68
% Generalist, Omnivores, Invertivores	≤ 80	> 80 - 99.9	> 99.9
Biomass per square meter	≥ 8.6	< 8.6 - 4	< 4.0
% Lithophilic Spawners	≥ 61	< 61 - 32	< 32

Project Name: Wheel Creek Monitoring 2022
Project Number: 161602035.06
Prepared by: SLF Checked by: AJB
Prepared date: 8/8/2022 Checked date: 11/10/2022

FIBI_WheelCrk_2022.xlsx

Site Name: ATKI-101-X-2022

Final ID	Scientific Name	Number of Organisms	Type	Tolerance	Trophic Status	Lithophilic Spawner	Composition	% Tolerant	% Generalists, Omnivores, Invertivores	Lithophilic Spawner	Adjusted No. Benthic Species	Abundance per Square Meter	Biomass per Square Meter
Redbreast Sunfish	*Lepomis auritus*	42	SUNFISH	NOTYPE	GE	N	NOTYPE	0	42	0	0	0.14	
Pumpkinseed	*Lepomis gibbosus*	8	SUNFISH	T	IV	N	NOTYPE	8	8	0	0	0.03	
Bluegill	*Lepomis macrochirus*	2	SUNFISH	T	IV	N	NOTYPE	2	2	0	0	0.01	
Largemouth Bass	*Mictopterus salmoides*	1	NOTYPE	T	TP	N	NOTYPE	1	0	0	0	0.00	
Creek Chub	*Semotilus atromaculatus*	75	OTHRCYPR	T	GE	Y	NOTYPE	75	75	75	0	0.25	
Bluntnose Minnow	*Pimephales notatus*	300	OTHRCYPR	T	OM	N	NOTYPE	300	300	0	0	1.01	
Blacknose Dace	*Rhinichthys atratulus*	144	OTHRCYPR	T	OM	N	NOTYPE	144	144	0	0	0.48	
Smallmouth Bass	*Micropterus dolomieu*	1	NOTYPE	NOTYPE	TP	N	NOTYPE	0	0	0	0	0.00	
Blue Ridge Sculpin	*Cottus caeruleomentum*	375	SCULPIN	I	IS	Y	B	0	0	375	1	1.26	
Common Shiner	*Luxilus cornutus*	58	SHINER	I	OM	Y	NOTYPE	0	58	58	0	0.19	
White Sucker	*Catostomus commersonii*	1	SUCKER	T	OM	Y	NOTYPE	1	1	1	0	0.00	
Swallowtail Shiner	*Notropis procne*	13	SHINER	NOTYPE	IV	Y	NOTYPE	0	13	13	0	0.04	
Green Sunfish	*Lepomis cyanellus*	8	SUNFISH	T	GE	N	NOTYPE	8	8	0	0	0.03	
Longnose Dace	*Rhinichthys cataractae*	3	OTHRCYPR	NOTYPE	OM	N	NOTYPE	0	3	0	0	0.01	
Cutlip Minnow	*Exoglossum maxillingua*	2	OTHRCYPR	NOTYPE	IV	Y	NOTYPE	0	2	2	0	0.01	
Eastern Mosquitofish	*Gambusia holbrooki*	42	NOTYPE	NOTYPE	IV	N	NOTYPE	0	42	0	0	0.14	
Satinfin Shiner	*Cyprinella analostana*	14	SHINER	I	IV	N	NOTYPE	0	14	0	0	0.05	
Fallfish	*Semotilus corporalis*	24	OTHRCYPR	I	GE	Y	NOTYPE	0	24	24	0	0.08	
Rosyside Dace	*Clinostomus funduloides*	1	OTHRCYPR	NOTYPE	IV	Y	NOTYPE	0	1	1	0	0.00	
	Total Count	*1114*						*48.38%*	*66.16%*	*49.28%*	*1.13*	3.74	*9.42*
	Total Biomass (g)	*2809*											

Project Name:	Wheel Creek Monitoring 2022		
Project Number:	161602035.06		
Prepared by:	SLF	Checked by:	AJB
Prepared date:	6/29/2022	Checked date:	11/10/2022

FIBI_WheelCrk_2022.xlsx

Site Name: ATKI-102-X-2022

Final ID	Scientific Name	Number of Organisms	Type	Tolerance	Trophic Status	Lithophilic Spawner	Composition	% Tolerant	% Generalists, Omnivores, Invertivores	Lithophilic Spawner	Adjusted No. Benthic Species	Abundance per Square Meter	Biomass per Square Meter
Blacknose Dace	*Rhinichthys atratulus*	431	OTHRCYPR	T	OM	N	NOTYPE	431	431	0	0	3.15	
Blue Ridge Sculpin	*Cottus caeruleomentum*	212	SCULPIN	I	IS	Y	B	0	0	212	1	1.55	
Creek Chub	*Semotilus atromaculatus*	193	OTHRCYPR	T	GE	Y	NOTYPE	193	193	193	0	1.41	
	Total Count	*836*						*74.64%*	*74.64%*	*48.44%*	*2.89*	6.11	*15.23*
	Total Biomass (g)	*2085*											

Project Name:	Wheel Creek Monitoring 2022		
Project Number:	161602035.06		
Prepared by:	SLF	Checked by:	AJB
Prepared date:	6/29/2022	Checked date:	11/10/2022

FIBI_WheelCrk_2022.xlsx

Site Name: ATKI-003-X-2022

KCI TECHNOLOGIES

Final ID	Scientific Name	Number of Organisms	Type	Tolerance	Trophic Status	Lithophilic Spawner	Composition	% Tolerant	% Generalists, Omnivores, Invertivores	Lithophilic Spawner	Adjusted No. Benthic Species	Abundance per Square Meter	Biomass per Square Meter
Blacknose Dace	*Rhinichthys atratulus*	139	OTHRCYPR	T	OM	N	NOTYPE	139	139	0	0	0.81	
Blue Ridge Sculpin	*Cottus caeruleomentum*	90	SCULPIN	I	IS	Y	B	0	0	90	1	0.52	
Creek Chub	*Semotilus atromaculatus*	215	OTHRCYPR	T	GE	Y	NOTYPE	215	215	215	0	1.25	
White Sucker	*Catostomus commersonii*	3	SUCKER	T	OM	Y	NOTYPE	3	3	3	0	0.02	
	Total Count	*447*						*79.87%*	*79.87%*	*68.90%*	*6.00*	2.59	*8.48*
	Total Biomass (g)	*1462*											

Project Name:	Wheel Creek Monitoring 2022		
Project Number:	161602035.06		
Prepared by:	SLF	Checked by:	AJB
Prepared date:	8/11/2022	Checked date:	11/10/2022

FIBI_WheelCrk_2022.xlsx

Site Name: LWIN-108-X-2022

KCI TECHNOLOGIES

Final ID	Scientific Name	Number of Organisms	Type	Tolerance	Trophic Status	Lithophilic Spawner	Composition	% Tolerant	% Generalists, Omnivores, Invertivores	Lithophilic Spawner	Adjusted No. Benthic Species	Abundance per Square Meter	Biomass per Square Meter
Blacknose Dace	*Rhinichthys atratulus*	69	OTHRCYPR	T	OM	N	NOTYPE	69	69	0	0	0.25	
Creek Chub	*Semotilus atromaculatus*	59	OTHRCYPR	T	GE	Y	NOTYPE	59	59	59	0	0.22	
Rosyside Dace	*Clinostomus funduloides*	19	OTHRCYPR	NOTYPE	IV	Y	NOTYPE	0	19	19	0	0.07	
Blue Ridge Sculpin	*Cottus caeruleomentum*	123	SCULPIN	I	IS	Y	B	0	0	123	1	0.45	
American Eel	*Anguilla rostrata*	16	NOTYPE	NOTYPE	GE	N	NOTYPE	0	16	0	0	0.06	
White Sucker	*Catostomus commersonii*	2	SUCKER	T	OM	Y	NOTYPE	2	2	2	0	0.01	
Longnose Dace	*Rhinichthys cataractae*	7	OTHRCYPR	NOTYPE	OM	N	NOTYPE	0	7	0	0	0.03	
Bluntnose Minnow	*Pimephales notatus*	4	OTHRCYPR	T	OM	N	NOTYPE	4	4	0	0	0.01	
	Total Count	*299*						*44.82%*	*58.86%*	*67.89%*	*1.10*	1.10	*5.77*
	Total Biomass (g)	*1569*											

Appendix D: Supplemental Flora/Fauana Data

ATKI-101-X

Invasive Plants	Relative Abundance
Japanese barberry	Present
Japanese stiltgrass	Extensive
Wineberry	Present
Japanese honeysuckle	Present
Garlic mustard	Present
Oriental bittersweet	Present
Multiflora rose	Present

Stream Salamanders
Nothern Two-lined Salamander

Other Herpetofauna
Northern green frog
American toad
Northern watersnake

Crayfish
Faxonius virilis

ATKI-102-X

Invasive Plants	Relative Abundance
Japanese honeysuckle	Present
Japanese stiltgrass	Extensive
Oriental bittersweet	Present
Multiflora rose	Present
Mile-a-minute	Present

Stream Salamanders
Nothern Two-lined Salamander

Other Herpetofauna
Northern green frog
Northern watersnake

Crayfish
Faxonius virilis

ATKI-003-X

Invasive Plants	Relative Abundance
Japanese stiltgrass	Extensive
Wineberry	Present
Garlic mustard	Present
Japanese barberry	Present
Oriental bittersweet	Present
Japanese honeysuckle	Present
Multiflora rose	Present
Mile-a-minute	Present
Privet	Present

Stream Salamanders
Northern Two-lined salamander

Other Herpetofauna
Northern green frog
Copes gray treefrog
merican bullfrog

Crayfish
Faxonius virilis

LWIN-108-X

Invasive Plants	Relative Abundance
Japanese stiltgrass	Present
Multiflora rose	Present

Stream Salamanders
Nothern Two-lined Salamander

Other Herpetofauna
None observed

Crayfish
None Observed

WHEEL CREEK
GEOMORPHIC ASSESSMENT
POST-RESTORATION YEAR 5
FINAL REPORT

October 27, 2022

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WHEEL CREEK
GEOMORPHIC ASSESSMENT
POST-RESTORATION YEAR 5 FINAL REPORT

Prepared for:

Harford County
Department of Public Works
Division of Highways and Water Resources
212 South Bond Street
Bel Air, Maryland 21014

Prepared by

Versar, Inc.
9200 Rumsey Road, Suite 1
Columbia, Maryland 21045

October 27, 2022

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1.0 INTRODUCTION

Harford County Department of Public Works (DPW) has completed the restoration of the Wheel Creek watershed, which is located in the Bush River Basin in the central portion of Harford County near Bel Air (Figure 1-1). The restoration is the result of previous planning efforts including the Bush River Watershed Restoration Strategy (WRAS), the Bush River Watershed Management Plan in 2003, and the Wheel Creek Watershed Assessment completed in 2008.

Restoration efforts in this watershed began in September 2012 with the retrofit of a stormwater management facility (Pond A) located at the Gardens of Bel Air, and construction was completed in December of 2012. A second project, the Calvert's Walk stream restoration project, began in January of 2013 and was completed that April. In 2015, two more stormwater management facilities were retrofitted, Pond C in August and Pond D in December. The final phase of implementation was completed in March of 2017. These projects included the Lower Wheel Creek stream restoration and the retrofit of the final stormwater management facility (Pond E). After several high intensity rain events since the completion of the Lower Wheel Creek stream restoration, portions of the restoration failed by 2021; the County secured a grant through the Army Corps of Engineers to repair this restoration and these repairs have been scheduled.

As part of implementing the restoration efforts, the County was awarded funds from a Local Government Implementation Grant through the Chesapeake and Atlantic Coastal Bays 2010 and 2016 Trust Funds. Under the grant proposal, the County planned to implement a total of four stormwater retrofits and five stream restoration projects to improve water quality, decrease stormwater discharges, and improve instream habitat.

Beginning in 2009, the County initiated monitoring to demonstrate measurable reductions of sediment and nutrients, improvement in physical stability and instream habitat, and improvement in fish and benthic macroinvertebrates communities. As a collaborative monitoring effort, Harford County DPW, Maryland Department of Natural Resources (DNR), the United States Geologic Survey (USGS), and two consulting firms (KCI Technologies and Versar, Inc.) have performed select data collection activities. The study design was developed to compare Pre-Construction conditions (i.e., baseline conditions) to future Post-Construction restoration conditions. This report focuses on nine years of geomorphic monitoring, conducted by KCI and Versar. Data generated by other project partners includes:

- USGS – flow gaging at the downstream end of Wheel Creek (5-minute interval discharge record);
- Maryland DNR (Up to July 2016)/Versar (July 2016 to present) – flow gaging at three stations, one at Wheel Road and two upstream on the eastern tributary at Cinnabar Lane and Wheel Court (5-minute interval discharge record);
- KCI – Biological and physical habitat data;

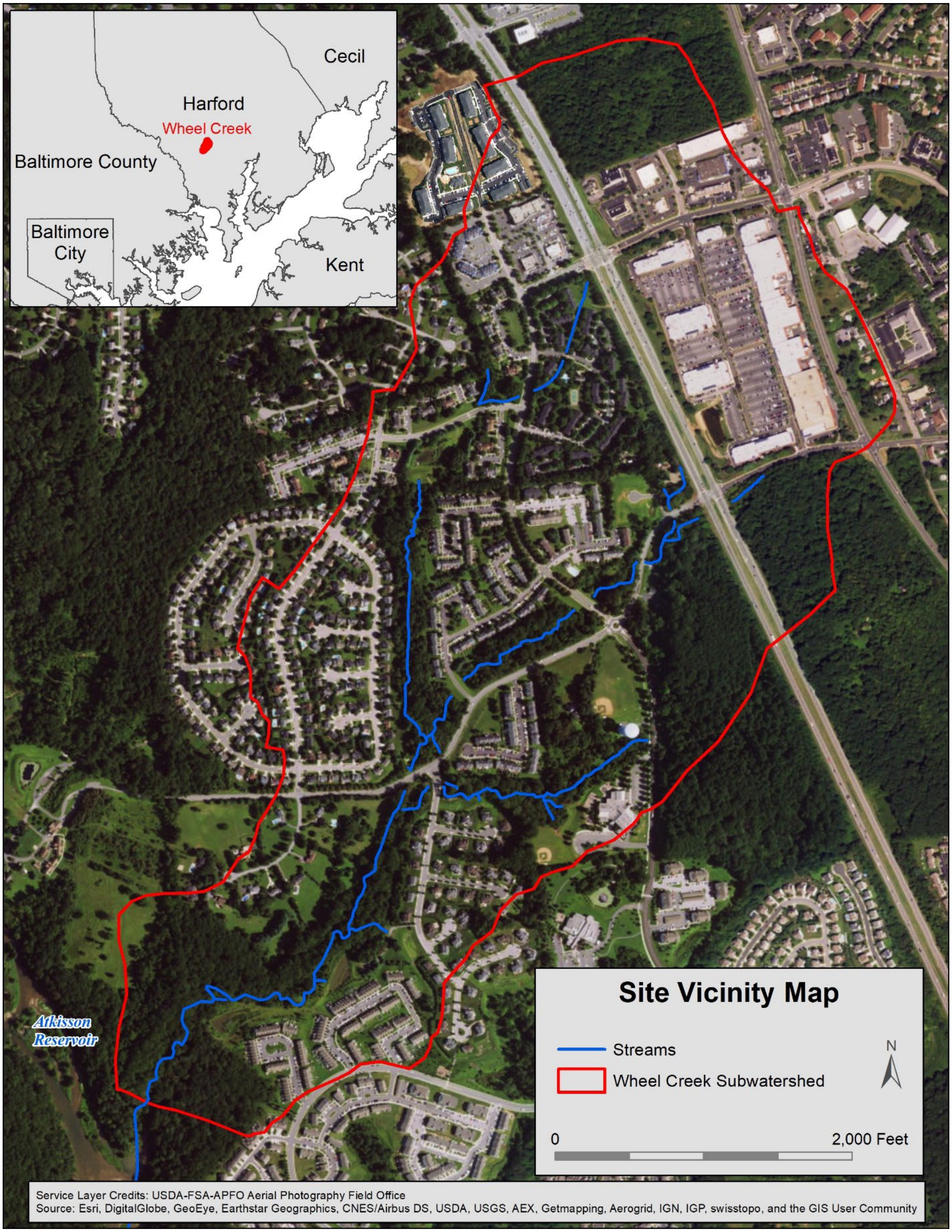

Figure 1-1. Site vicinity map

- Versar – Storm runoff water chemistry and water quality monitoring including nutrient and sediment data at three stations, one at Wheel Road and two upstream on the eastern tributary at Cinnabar Lane and Wheel Court (pollutant loads for the measured parameters for each sampled event); and
- Harford County DPW (Up to March 2019)/Versar (April 2019 to present) – Baseflow nutrient and total suspended solids data at three stations, one at Wheel Road and two upstream on the eastern tributary at Cinnabar Lane and Wheel Court.

Assessment and monitoring of the physical geomorphologic conditions was initially performed by KCI in 2010 (Pre-Restoration Year 1) to evaluate baseline conditions and was continued by Versar in 2012 (Pre-Restoration Year 2), 2013 (Pre-Restoration Year 3), 2015 (Pre-Restoration Year 4), 2017 (Post-Restoration Year 1), 2018 (Post-Restoration Year 2), 2019 (Post-Restoration Year 3), 2020 (Post-Restoration Year 4), and 2022 (Post-Restoration Year 5). The geomorphic monitoring program was designed to assess the geomorphic stability of the stream channels in the Wheel Creek watershed as they respond to restoration activities. The geomorphic monitoring includes surveying and analyzing monumented cross-sections and longitudinal profiles at four (4) reaches (Pre-Restoration Years 1 through 4 and Post-Restoration Years 1 through 5), monitoring bank pins and scour chains (Pre-Restoration Year 1 through 4 only), mapping substrate facies (Pre-Restoration Year 1 only), and evaluating substrate particle size distribution (Pre-Restoration Years 1 through 4 and Post-Restoration Years 1 through 5). The methods evaluate bed and bank stability, channel profile, and bed features. For a complete description of the Year 1 Study see *Wheel Creek Watershed Restoration Project, Pre-Construction Monitoring, Baseline Conditions, 2009-2011* (KCI, 2012). For a complete description of the Year 2, Year 3, and Year 4 Studies see *Wheel Creek Geomorphic Assessment Year 2* (Versar, 2013), *Wheel Creek Geomorphic Assessment Year 3* (Versar, 2014) and *Wheel Creek Geomorphic Assessment Year 4* (Versar, 2015). For a complete description of the Post-Restoration Year 1 Study see *Wheel Creek Geomorphic Assessment Post-Restoration Year 1 Final Report* (Versar, 2017), Year 2 Study see *Wheel Creek Geomorphic Assessment Post-Restoration Year 2 Final Report* (Versar, 2018), Year 3 Study see *Wheel Creek Geomorphic Assessment Post-Restoration Year 3 Final Report* (Versar, 2019), and Year 4 Study see *Wheel Creek Geomorphic Assessment Post-Restoration Year 4 Final Report* (Versar, 2020). This report focuses on continued geomorphic monitoring, including a comparison of data collected during Pre-Restoration Years 1, 2, 3, 4, and Post-Restoration Years 1, 2, 3, 4, and 5.

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2.0 METHODOLOGIES

2.1 GEOMORPHIC ASSESSMENT

The primary goal of the geomorphic monitoring is to assess the geomorphic stability of the stream channels in the Wheel Creek watershed as they respond to restoration activities. Assessment techniques include a survey of permanently-monumented channel cross-sections, a longitudinal profile survey, particle size analysis, substrate facies mapping (Pre-Restoration Year 1 only), and assessment of bank pins and scour chains (Pre-Restoration Years 1 through 4 only). In 2010, four (4) assessment reaches (Figure 2-1) were established by KCI for geomorphic monitoring based on the following treatments:

1. within a stream stabilization reach (WC01);
2. within a stream stabilization reach and downstream of a retrofitted stormwater management facility (WC02);
3. downstream of a retrofitted stormwater management facility (WC03); and
4. a control site with no proposed restoration activities (WC04).

These reaches were re-surveyed by Versar in 2012, 2013, 2015, 2017, 2018, 2019, 2020, and 2022 to provide additional monitoring data. Cross-sectional and longitudinal profile surveys were first conducted to establish baseline conditions of channel geometry and slope. Subsequent survey data can be compared to the baseline data to determine whether lateral or vertical migration of the channel is occurring and to document any changes that have occurred in the restored reaches. Bank and bed pins were monitored to determine rates of potential bank and channel bed erosion or aggradation, while scour chains were used to quantify the extent of bed material scouring. The bank and bed pins along with the scour chains have been discontinued from the monitoring following Pre-Restoration Year 4 (2015). Pebble counts were conducted to assess substrate particle size distribution and track changes in channel roughness. Detailed methods are described below.

2.1.1 Longitudinal Profile and Cross-sectional Surveys

KCI installed and surveyed three (3) benchmark monuments at each reach during the initial baseline monitoring effort (2010) to establish consistent survey elevations from year to year, as well as start and end points for each survey reach. Two benchmarks (one concrete monument and one capped iron rebar pin) were placed on either side of the channel, whereby a measuring tape run from the left bank pin to the right bank monument marks the starting point (i.e., station 0+00) in the channel for the longitudinal profile. The concrete monument was set in 2-inch PVC piping to a depth of 30 inches, with a rounded stove bolt set in the concrete to establish the monumented benchmark elevation, which will be used to compare longitudinal profiles over time. A third monument (capped iron rebar) was placed at the upstream end of the reach to mark the end of the survey reach. Versar re-surveyed these benchmarks at WC03 and WC04 during the Post-Restoration Years 1, 2, 3, 4, and 5 efforts to enable overlays between past surveys.

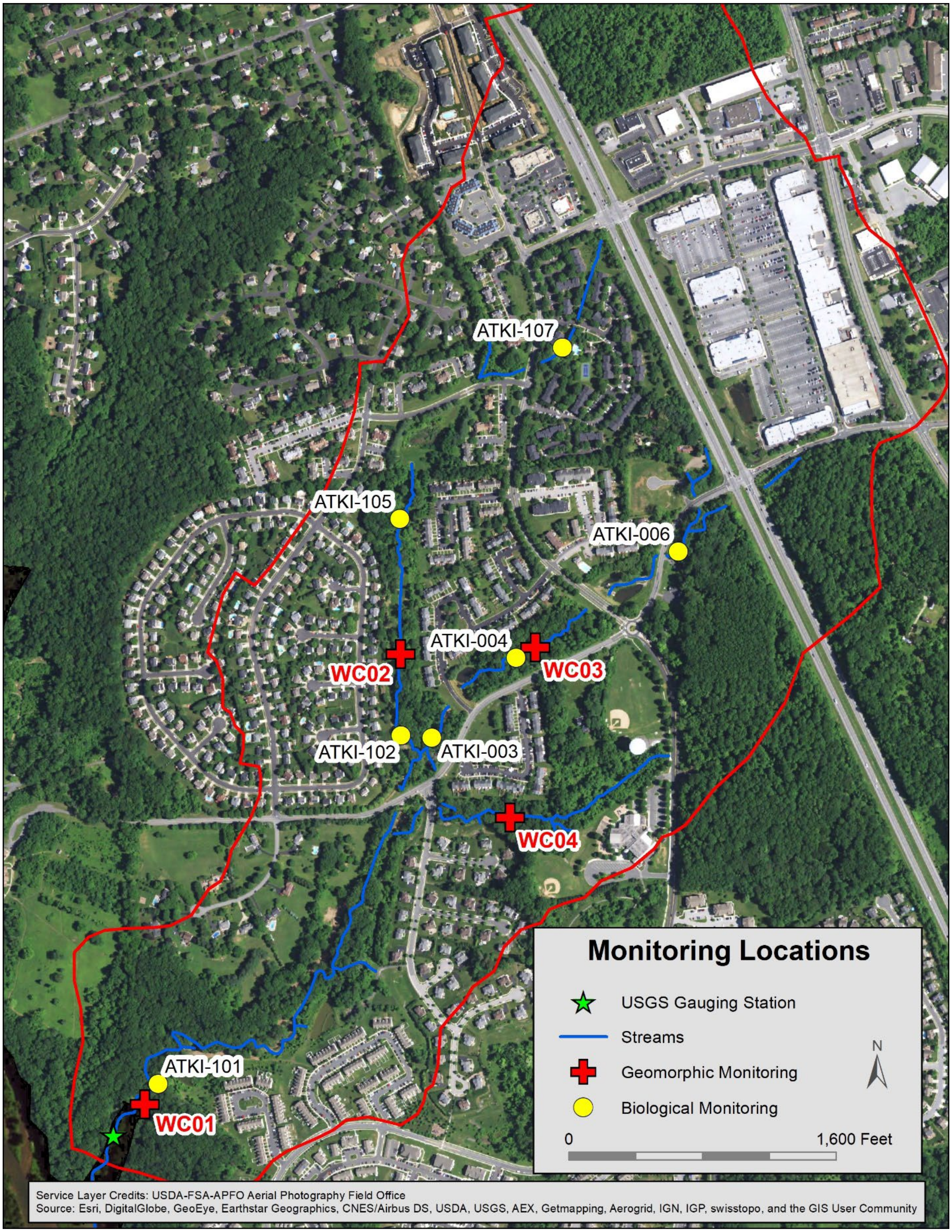

Figure 2-1. Wheel Creek monitoring locations

Versar re-established reaches WC01 and WC02 in 2017 for Post-Restoration Year 1 monitoring. Three (3) benchmark monuments were again installed at both reaches. Two capped iron rebar monuments were installed on each side of the channel to mark the starting point of the new longitudinal profile (i.e., station 0+00). An additional capped iron rebar monument was installed upstream marking the end of the longitudinal profile. These were re-surveyed in 2018, 2019, 2020, and 2022. During the Post-Restoration Year 5 survey in 2022, the right start pin at the 0+00 station of the WC03 longitudinal profile could not be located by field crews; a new capped pin was set and surveyed against the existing left start pin to allow for elevation adjustments and consistent comparisons of data in future surveys.

A longitudinal profile of each reach was surveyed using a laser level, calibrated stadia rod, and 300-foot measuring tape following the procedure outlined in Harrelson et al. (1994). The longitudinal profiles were initially established to encompass a minimum reach length of approximately 20 bankfull widths or 300 feet, measured along the centerline of each bankfull channel. Each reach was started at the top of a feature located at the downstream benchmarks, and finished at the top of a feature at or above the upstream benchmark. Each reach included a survey of breakpoints in and between bed features and delineation of riffle, run, pool, and glide features. A survey of the bankfull elevation (where discernible), top of bank, and water surface was also performed. At each site where instream restoration activities did not occur (WC03 and WC04), the plotted Post-Restoration Years 1 through 5 longitudinal profiles were overlaid with the plots from Pre-Restoration Years 1 through 4. These plots enable comparisons between years and are used to track changes that occur in the bed sequences and channel slopes. At the two sites where instream restoration occurred (reaches WC01 and WC02), the plotted profiles from Pre-Restoration Years 1 through 4 were overlaid and the Post-Restoration Years 1 through 5 plotted profiles were compared.

In order to establish locations where fluvial geomorphic characteristics of the channel could be measured and compared from one year to the next for assessing bed and bank stability, KCI established permanent cross-sections at two (2) locations within each monitoring reach during Pre-Restoration Year 1; one located on a meander bend and one within a riffle feature. KCI established monuments (one concrete and one capped iron rebar) on either side of the channel to mark the cross-section locations and benchmark elevations. Concrete monuments were set in 2-inch PVC piping to a depth of 30 inches, with a rounded metal stove bolt set in the concrete to mark the monumented elevation. Wherever possible, the monuments were set flush to the ground surface for safety concerns, and the location of each monument was recorded using a GPS unit capable of sub-meter accuracy.

Permanent cross-sections were established in 2010 and surveyed during Pre-Restoration Years 1 through 4 and Post-Restoration Years 1 through 5 within each reach at profile stations as shown in Table 2-1. Stationing differed slightly at several stations due to channel migration over time or as a result of re-installing a cross-section when instream restoration has occurred. Cross-sections located in reaches WC01 and WC02 were re-established with new benchmarks in Post-Restoration Year 1 (2017). Due to ongoing restoration construction activities, the WC01 left end pin at Cross-section 2 had to be reinstalled in 2018, as it could not be located during the Post-

Restoration Year 2 survey. Reaches WC03 and WC04 were still monumented to the original benchmarks installed in Pre-Restoration Year 1 (2010) since no instream restoration occurred at those locations. However, the WC03 right end pin at Cross-section 2 had to be reinstalled in 2019, as it had eroded away and fallen into the stream channel during the Post-Restoration Year 3 survey. The same methods were used to establish the new cross-sections in these reaches, although the corresponding station on the longitudinal profile will not be comparable to previous years of Pre-Restoration surveying.

Table 2-1. Cross-sectional survey locations

Reach	WC01*		WC02*		WC03		WC04	
Profile Station (Pre-Year 1)	2+30	2+95	1+37	3+24	1+55	2+07	1+08	1+68
Profile Station (Pre-Year 2)	2+30	2+95	1+38	3+24	1+57	2+08	1+08	1+68
Profile Station (Pre-Year 3)	2+29	2+95	1+38	3+25	1+56	2+12	1+08	1+68
Profile Station (Pre-Year 4)	2+29	2+95	1+38	3+24	1+55	2+07	1+08	1+68
Profile Station (Post-Year 1)	2+24	2+71	0+74.5	1+10	1+56	2+08	1+10	1+68
Profile Station (Post-Year 2)	2+24	2+71	0+74.5	1+10	1+56	2+08	1+10	1+68
Profile Station (Post-Year 3)	2+24	2+71	0+74.5	1+10	1+56	2+08	1+10	1+68
Profile Station (Post-Year 4)	2+24	2+71	0+74.5	1+10	1+56	2+08	1+10	1+68
Profile Station (Post-Year 5)	2+24	2+71	0+74.5	1+10	1+56	2+08	1+10	1+68
Feature	Riffle	Meander/ Pool	Riffle	Pool	Riffle	Meander/ Run	Meander/ Pool	Riffle

*Cross-sections re-established during Post-Restoration Year 1

During Post-Restoration Year 5, Versar resurveyed the cross-sections using a laser level, calibrated stadia rod, and measuring tape following the procedure outlined in Harrelson et al. (1994). The cross-sectional surveys captured features of the floodplain, monuments, and all pertinent channel features including:

- Top of bank
- Bankfull elevation
- Edge of water
- Limits of point and instream depositional features
- Thalweg
- Floodprone elevation

Longitudinal profile and cross-sectional data were entered into *The Reference Reach Spreadsheet* version 4.3L (ODNR, 2012) for data analysis and graphical interpretation. Profile and cross-sectional data collected in 2010, 2012, 2013, 2015, 2017, 2018, 2019, 2020, and 2022 provide nine years of data to which subsequent monitoring events will be overlaid and/or compared to assess changes in channel dimension, pattern, and profile.

For the purpose of this report, bankfull elevations were selected based upon bankfull indicators observed in the field. Channel geometry and cross-sectional areas were calculated using *The Reference Reach Spreadsheet* (ODNR, 2012). Because bankfull indicators are not always easily discernible from year to year and best professional judgment is often required to determine bankfull elevations, top of bank features were also measured. Top of low bank cross-sectional areas were also calculated and can be utilized for future monitoring events to generate hydraulic geometry values that are more directly comparable between each monitoring effort.

2.1.2 Particle Size Analysis

Channel substrate composition (e.g., gravel, sand, silt) is an important aspect of a stream's biological and geomorphic character. The substrate size and complexity affects the stream's available habitat for benthic fauna and determines a channel's roughness, which influences the channel flow characteristics. To quantify the distribution of channel substrate particle sizes within the study area, modified Wolman pebble counts (Wolman, 1954; Harrelson et al., 1994) were performed. A total of three (3) pebble counts were conducted within each monitoring reach; one (1) feature-specific pebble count was conducted at each cross-section location within the cross-sectional bed feature (two [2] total within each reach), and one (1) weighted pebble count was conducted throughout the entire reach based on the proportion of bed features (e.g., riffle, run, pool, glide) present within the survey reach. Feature-specific pebble counts were performed via 10 evenly-spaced transects positioned throughout the survey feature, and 10 particles (spaced as evenly as possible) were measured across the bankfull channel of each transect for a total of 100 particles. The weighted (proportional) pebble count was conducted at 10 transects positioned throughout the entire reach based on the proportion of bed features, and 10 particles (spaced as evenly as possible) were measured across the bankfull channel of each transect for a total of 100 particles. For both types of counts, particles were chosen without visual bias by reaching forth with an extended finger into the stream bed while looking away and choosing the first particle that comes in contact with the sampler's finger. All particles were then measured across the intermediate axis using a gravelometer and resultant data were entered into *The Reference Reach Spreadsheet* (ODNR, 2012). The results of each weighted pebble count were used to determine the median particle size (i.e., D_{50}) of the specific reach. Additionally, the D_{84} was calculated from the feature pebble counts to determine the particle size that 84 percent of the sample is of the same size or smaller. The D_{84} particles were used in calculating channel velocity and discharge. Results from Versar's Post-Restoration Year 5 evaluations were compared to those found during the previous years of monitoring to evaluate changes in channel substrate composition and stability.

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3.0 RESULTS AND DISCUSSION

3.1 FLUVIAL GEOMORPHIC ASSESSMENT

3.1.1 Longitudinal Profiles and Cross-sectional Surveys

The fifth year of Post-Restoration longitudinal profile and cross-sectional surveys was completed between May 5th and June 28th, 2022. While performing the longitudinal profile, bed features including riffles, runs, pools, glides, bankfull indicators (where readily discernible), and water surface were noted to sufficiently assess conditions. The longitudinal profile data were analyzed to calculate the water surface slope and proportion of bed features for each monitoring reach (Table 3-1). These data will be compared to previous and subsequent annual monitoring data to track potential changes in the overall channel slope. Refer to Appendix A for photographs depicting the overall site conditions during the Post-Restoration Year 5 survey. Graphical depictions of each profile are presented in Appendix B. In addition, each surveyed profile was plotted, but only overlain and compared to the Pre-Restoration Years 1, 2, 3, and 4 profiles at WC03 and WC04 (Appendix C) and will be compared to subsequent annual surveyed profiles in order to assess changes occurring in the bed structure. Due to instream restoration activities, WC01 and WC02 Post-Restoration overlays do not share the same monuments as Pre-Restoration. Therefore, separate Post-Restoration overlays were created for these reaches.

Table 3-1. Results of longitudinal profile survey – Post-Restoration Year 5

Reach	Length (ft)	Slope	Proportion of Features			
			Riffle	Run	Pool	Glide
WC01*	490	2.7%	38.4 %	26.8%	18.9%	15.9%
WC02*	340	2.3%	45.7%	27.6%	14.6%	12.1%
WC03	308	1.8%	49.0%	17.1%	28.2%	5.8%
WC04	300	3.6%	67.4%	13.5%	12.2%	7.0%

*Profiles re-established during Post-Restoration Year 1

Cross-sectional surveys were analyzed at each of the eight permanent monitoring locations to determine bankfull width, mean depth, width/depth ratio, and overall cross-sectional area during baseline conditions. Since bankfull elevation is based on field indicators and can be somewhat subjective to determine in the field, top-of-bank elevation was also calculated and will be utilized to track changes in the cross-sectional dimensions listed below. Results of the cross-sectional measurements are included in Table 3-2 and graphical depictions of each section are presented in Appendix B. In addition, each surveyed section was plotted, overlain (where appropriate) and compared to the Pre-Construction year 1, 2, 3, and 4 graphs (Appendix C) and will be compared to subsequent annual cross-section graphs in order to assess changes to channel dimensions post-restoration.

Table 3-2. Results of cross-sectional survey analysis – Post-Restoration Year 5								
Reach	**Station**	**Feature**	**Bankfull Width (ft)**	**Mean Depth (ft)**	**Width/ Depth Ratio**	**Entrench-ment Ratio**	**Bankfull Area (ft^2)**	**Top of Bank Area (ft^2)**
WC01*	2+24	Crossover/Riffle	24.1	0.9	27.1	1.6	21.4	131.1
	2+71	Meander/Pool	13.1	1.4	9.3	2.1	18.5	111.3
WC02*	0+74.5	Crossover/Riffle	14.3	0.3	47.8	1.3	4.3	22.9
	1+10	Pool	12.2	0.6	22.0	1.1	6.8	35.4
WC03	1+56	Crossover/Riffle	10.4	0.7	13.9	1.3	7.8	42.4
	2+08	Meander/Run	14.7	1.2	12.1	2.4	17.9	34.8
WC04	1+10	Meander/Pool	7.6	0.8	9.9	4.2	5.8	80.3
	1+68	Crossover/Riffle	11.0	0.4	27.1	1.4	4.4	55.5
*Cross-sections were re-established during Post-Restoration Year 1								

3.1.2 Particle Size Analysis

The results of the pebble count data collected during the Post-Restoration Year 5 monitoring are shown in Table 3-3. Reachwide, meander, and riffle surface pebble counts indicate a D_{50} median particle size class ranging from medium gravel to small cobble across all sites. Meander feature surface pebble count D_{50} median particle yield smaller particles due to pool features which is especially evident at the WC01 and WC03 meander/pool cross-sections. Riffle surface and reachwide D_{84} size classes range from very coarse gravel to large cobble at all sites, with the largest particles found at sites WC01 and WC02. Similarly, meander feature surface pebble counts at all sites indicate a D_{84} median particle size class ranging from very coarse gravel to medium cobble. Complete particle size distribution charts are included in Appendix B.

Table 3-3. Particle size distribution – Post-Restoration Year 5								
Riffle Feature Surface			***Meander Feature Surface***			***Reachwide***		
Measure	**Size (mm)**	**Size Class**	**Measure**	**Size (mm)**	**Size Class**	**Measure**	**Size (mm)**	**Size Class**
*WC01**								
D_{50}	83	small cobble	D_{50}	68	small cobble	D_{50}	82	small cobble
D_{84}	170	large cobble	D_{84}	120	medium cobble	D_{84}	160	large cobble
*WC02**								
D_{50}	28	coarse gravel	D_{50}	34	very coarse gravel	D_{50}	43	very coarse gravel
D_{84}	61	very coarse gravel	D_{84}	68	small cobble	D_{84}	88	small cobble
WC03								
D_{50}	28	coarse gravel	D_{50}	20	coarse gravel	D_{50}	21	coarse gravel
D_{84}	61	very coarse gravel	D_{84}	47	very coarse gravel	D_{84}	56	very coarse gravel
WC04								
D_{50}	19	coarse gravel	D_{50}	15	medium gravel	D_{50}	11	medium gravel
D_{84}	41	very coarse gravel	D_{84}	58	very coarse gravel	D_{84}	34	very coarse gravel

4.0 COMPARISONS BETWEEN YEARS

4.1 WC01

This site exhibited the most drastic changes in longitudinal profile over the four years of Pre-Restoration monitoring (2010-2015; Figure C-1). At the downstream-most part of the reach, the stream's thalweg followed along the left bank outside bend during the first year of survey with a large mid-channel bar separating the thalweg from a cutoff channel along the right bank. During the second and third years of monitoring (2012, 2013), the thalweg followed what had been the cutoff channel along the right bank and the previous thalweg channel had only minimal flows. During the fourth year of survey (2015) the thalweg continued to follow the channel along the right bank. Furthermore, a large tree along the left bank fell and was perpendicularly positioned in the stream through this section. The tree caused the stream to widen and flow over most of the mid-channel bar; however, during years 1 through 3 of Post-Restoration monitoring, the tree migrated onto the left bank, laying parallel, and the outside left bend channel now conveyed the majority of stream flow (Figure C-2). During the year 4 Post-Restoration survey in 2020, channel conditions at this location were found to have aggraded substantially with the majority of stream flow found mid-channel throughout this portion of the profile. The fifth year of Post-Restoration monitoring found that the mid-channel bar had formed again in this portion of the reach, with equal flow conveyed on either side. At the upstream-most part of the reach, the stream's pattern also changed. Stationing differed from above Cross-section 2 (Station 2+95) to the end of the reach. During Pre-Restoration monitoring the reach was 420 feet from top to bottom, but during Post-Restoration years the reach was 490 feet in length. Sinuosity above Cross-section 2 likely increased, adding length to the profile.

Changes in the cross-sections were also observed at WC01 between the four years of Pre-Restoration survey (Figures C-7, C-9). Bed scour was observed at Cross-section 1 (Crossover Riffle at Station 2+29) especially near the right bank between Pre-Restoration Years 1 and 2, while deposition was apparent near the left bank between Pre-Restoration Years 2 and 3. During Pre-Restoration Year 4, continued deposition was observed, and the cross-section once again closely resembled that of Pre-Restoration Year 1. Significant bank erosion and undercutting along the left bank (almost 6 feet) was observed at Cross-section 2 (Meander Bend at Station 2+95) during both the second and third years of monitoring (2012, 2013). Between Pre-Restoration Years 3 and 4, continued erosion occurred along the left bank increasing the depth of undercutting. Eroded sediment caused slight deposition along the left stream bed. This resulted in increases, from Pre-Restoration Year 1, of bankfull cross-sectional area and top of bank cross-sectional area at this station. Between Pre-Restoration Years 1 and 2, a side-bar formed on the right bank, burying the scour chain at this cross-section. The scour chain was not found during Pre-Restoration Years 3 and 4 of monitoring. In addition, the thalweg pattern changed between Pre-Restoration Years 1 and 2 so that it was no longer perpendicular to the permanently monumented cross-section markers at this location.

The first year of Post-Restoration monitoring was completed in 2017. The WC01 reach underwent an instream restoration and a new longitudinal profile and two cross-sections were selected and monitored for baseline conditions. Cross-section 1 was placed in a crossover riffle at Station 2+24, while Cross-section 2 was placed at a meander bend/pool at Station 2+71. The survey of the longitudinal profile consisted of large riffle and pool features. During 2017, approximately 55.1% of the reach was riffle/run and 44.9% was pool/glide; in 2018, approximately 57.0% of the reach was riffle/run and 43.0% was pool/glide. During 2019, approximately 59.3% of the reach was riffle/run and 40.7% was pool/glide; in 2020, approximately 52.8% of the reach was riffle/run and 47.2% was pool/glide. The longitudinal profile consisted of 65.1% riffle/run and 34.9% pool/glide. The slope of the reach was high at 2.6% in 2017 and remained high at 2.7% from 2018 through 2022. The cross-sections featured stable banks exhibiting no erosion. Cross-section 1 at Station 2+24 has a defined bench and access to a small floodplain as the banks have been graded back during construction (Figure C-8). Cross-section 2 at Station 2+71 exhibits the same floodplain on the right bank in addition to a point bar, while the left bank is heavily armored by boulders (Figure C-10); between the Post-Restoration years 3 through 5 surveys, this armoring failed, resulting in several of the large boulders eroding out and falling into the stream channel, leaving the bank behind exposed to future erosion. Channel alterations were noted between the 2017 and 2018 Post-Restoration surveys. Minimal scouring (approximately 0.25 feet) of the channel at Cross-section 1 was observed, while significant aggradation of sediment was found along the right bank and channel at Cross-section 2. These changes in streambed were likely the result of an abnormally wet spring, and year overall, which shifted and transported large amounts of sediment throughout the reach. Between the 2018 and 2019 Post-Restoration surveys, channel alteration was again noted. Aggradation of approximately 1.0 feet occurred in the middle of the channel at Cross-section 1, and approximately 1.0 feet of sediment was deposited on the right bank bench was observed; significant aggradation of sediment was found along the right bank and channel at Cross-section 2. Channel alteration was again noted between the 2019 and 2020 Post-Restoration surveys. The channel was noted to have scoured between 0.5 and 0.75 feet across much of the channel at Cross-section 1, and approximately 0.5 feet of scouring of the bench on the right bank was observed; significant scouring of approximately 1.0 feet was found along the left and right banks, with mid-channel conditions remaining the same, at Cross-section 2. The changes in streambed were significant between 2020 and prior year surveys, likely the result of extensive rains which shifted and transported large amounts of sediment throughout the reach. Between 2020 and 2022 surveys, conditions at Cross-section 1 remained stable, with minimal scouring (approximately 0.25 feet) noted mid- to right channel. More significant changes in channel geometry were noted at Cross-section 2 between 2020 and 2022. The armoring on the left bank slumped about 0.5 feet, further demonstrating the ongoing failure of the restoration in this portion of the reach, while significant aggradation (0.5-0.6 feet) of sediment was measured mid- to left-channel. The right side of the channel and floodplain remained stable between 2020 and 2022. Future surveys will be useful in determining how the stream channel reacts to these changes, how it stabilizes over time, and the success of the planned restoration repair in this reach.

At WC01, D_{50} particle size classes remained the same between all four years of Pre-Restoration study at both cross-sections, and reachwide (Table C-3). D_{84} particle size classes changed between Years 1 and 2, coarsening at Cross-section 1 (Crossover Riffle at Station 2+29) from medium to large cobble, and becoming slightly finer at Cross-section 2 (Meander Bend at Station 2+95) from medium to small cobble. Although D_{84} classes at Cross-section 2 were unchanged between Years 2 and 3 they transformed during the fourth year of study, increasing from small cobble to medium cobble. Reachwide D_{84} particle size class fluctuated between large cobble during Year 1, to medium cobble during Year 2 and back to large cobble during Years 3 and 4.

In the first year of Post-Restoration (2017), D_{50} particle sizes decreased from very coarse gravel to medium gravel at the meander feature and from very coarse gravel to coarse gravel reachwide. In Post-Restoration Years 2 and 3, reachwide D_{50} particle sizes increased back to very coarse gravel reachwide but fluctuated between medium and very coarse gravel at the meander feature. D_{50} particle sizes categorized as coarse gravel at both the meander feature and reachwide in Post-Restoration Year 4. Median particle size coarsened to small cobble reachwide and at the meander feature in Post-Restoration Year 5. Riffle feature surface D_{50} particle sizes remained as very coarse gravel during the first 4 years of post-restoration monitoring but coarsened to small cobble in Post-Restoration Year 5. In the first year of Post-Restoration monitoring (2017), reachwide D_{84} decreased to small cobble. The new crossover riffle at Station 2+24 had a D_{84} of small cobble and the new meander bend/pool at Station 2+71 had a D_{84} of very coarse gravel. In 2018, the reachwide D_{84} increased to large cobble. The crossover riffle at Station 2+24 had an increased D_{84} to large cobble and the meander bend/pool at Station 2+71 had an increased D_{84} to medium cobble. In 2019, the reachwide D_{84} decreased to small cobble. The crossover riffle at Station 2+24 had a decreased D_{84} to very coarse sand and the meander bend/pool at Station 2+71 had a decreased D_{84} to medium gravel. This overall decrease in particle size classes at WC01 was likely the result of an increase in smaller particles being transported and deposited into the reach from the above average rainfall received between 2018 and 2019. In 2020, the reachwide D_{84} increased to medium cobble. The crossover riffle at Station 2+24 had an increased D_{84} to medium cobble at the meander bend/pool at Station 2+71 had an increased D_{84} to small cobble. In Post-Restoration Year 5, D_{84} values increased one class at all three locations, coarsening to medium cobble and the meander bend/pool at Station 2+71 and large cobble at both the crossover riffle at Station 2+24 and reachwide. This overall increase in particle size classes at WC01 was likely the result of an increase in larger particles being transported and deposited into and within the reach from the above average rainfall intensities between 2019 and 2022, with enough power to redistribute larger substrate, as evidenced by the movement of the large armoring boulders at Station 2+71.

4.2 WC02

Significant changes in profile were not observed at WC02 over the four years of Pre-Restoration study. The most noticeable change is a pool feature once approximately at Station 1+00 changed to Station 0+80 (Figures C-3 and C-4). Reach length remained constant and stream slope measurements were fairly consistent overall. Feature proportions within the reach have fluctuated from year to year. While the percentage of glides increased from 0% to 16.7% between Pre-Restoration Years 1 and 2, the percentage of pools declined each year. During the fourth year (2015), 25.5% of the surveyed reach was classified as pools and glides, the lowest percentage since monitoring began. In contrast, riffles and runs made up 74.5% of the surveyed reach which was the greatest percentage of all four years (Table C-1).

Following Pre-Restoration Year 1, bed aggradation occurred at Cross-section 1 (Crossover Riffle at Station 1+38), but banks here remained relatively stable (Figure C-11). There was little change between the third and fourth year of Pre-Restoration study. Conversely, channel scour occurred at Cross-section 2 (Meander Bend at Station 3+24), as well as slight erosion of the upper portion of the right bank (Figure C-13). At this station, a bankfull bar exists along the left bank which showed little change between Pre-Restoration Years 2 and 3 of the study. However, during the fourth year of Pre-Restoration monitoring slight degradation can be seen along the left bank and bar.

In the first year of Post-Restoration monitoring, the WC02 reach consisted of 63.6% riffle/run and 36.4% pool/glide (Table C-1). This reach consisted of 60.3% riffle/run and 39.7% pool/glide in the 2018 Post-Restoration monitoring. During 2019 Post-Restoration monitoring, this reach consisted of 61.5% riffle/run and 38.5% pool/glide; the percent riffle/run and percent pool/glide was 59.0% and 41.0% during the 2020 Post-Restoration monitoring, respectively. In the fifth year of Post-Restoration monitoring, WC02 consisted of 73.3% riffle/run and 26.7% pool/glide, a significant change from the gradual decline in riffle/run features seen in the first four years of post-restoration monitoring and similar to the last year of pre-restoration monitoring (2015). This reach underwent instream restoration that has straightened the channel causing the meander bend cross-section to be placed in a straight pool. Overall, this reach is still somewhat lacking access to an immediate floodplain, but the banks are stable and well-vegetated despite being steep and high. The entrenchment ratio was low, 1.3, in 2017, and remained low at 1.4 in 2018 and 2019, and 1.3 in 2020 and 2022, indicating the stream is confined within the banks (Appendix B). The stream is comprised predominately of long riffles and grade control steps into long/wide pools. Cross-section 1 was newly monumented in a pool at Station 0+74.5 (Figure C-12) and Cross-section 2 was monumented at Station 1+10 in a crossover riffle (Figure C-14). Both cross-sections exhibit little bank erosion and have stable banks. Cross-section 1 aggraded substantially in 2018, with more than 1.5 feet of substrate deposited in the stream channel. Significant aggradation continued in 2019, with an additional 0.5 feet of sediment deposited in the stream channel; conditions at Cross-section 1 were comparable between the 2019 and 2022 surveys, indicating that this portion of the reach may have stabilized post-restoration. Cross-section 2 had minimal scouring (0.25 to 0.5 feet) within the channel in 2018, but experienced aggradation of 0.25 to 1.0 feet of substrate in 2019. Aggradation at this station continued in 2020, with an additional 0.25 feet of sediment being deposited. In the 2022 survey, Cross-section 2 was found to be largely similar to conditions in 2020, with particles being redistributed across the reach; approximately 0.25 feet of sediment was scoured from the right side of the channel while aggradation of approximately 0.25 feet of sediment was noted on the left side of the channel. These changes in streambed could be the result of an abnormally wet years overall between 2018 and 2022, which likely shifted and transported large amounts of sediment throughout the reach. Future surveys will enable evaluation of how the stream channel reacts to these changes, as well as how it stabilizes over time.

D_{50} particle size classes remained the same between all four years of Pre-Restoration study at both cross-sections. The reachwide D_{50} for Pre-Restoration Years 2 and 3 were categorized as coarse gravel which is slightly finer than the very coarse gravel observed in Pre-Restoration Years 1 and 4 (Table C-3). D_{84} particle size classes became slightly finer at both cross-sections, diminishing from medium-sized cobble to small cobble between the first and second years of Pre-Restoration study. Furthermore, both cross-section D_{84} classes coarsened between Pre-Restoration Years 3 and 4 from small cobble to medium cobble. Although reachwide D_{84} particle sizes also reduced between Pre-Restoration Years 1 and 2, particles increased back to medium-sized cobble in Pre-Restoration Year 3 and remained during Pre-Restoration Year 4.

In the first year of Post-Restoration study (2017), D_{50} particle size classes decreased at both cross-sections and reachwide, classifying as coarse gravel at the riffle feature, very fine gravel at the meander feature, and medium gravel reachwide. Riffle feature D_{50} classification rebounded back into the very coarse gravel category in the Post-Restoration Years 2 and 3 surveys, and meander feature D_{50} particle sizes coarsened to small cobble in 2018 and medium gravel in 2019. In the Post-Restoration Year 4 survey, riffle feature D_{50} coarsened to small cobble and meander feature D_{50} coarsened to very coarse gravel. Reachwide D_{50} classifications rated as very coarse gravel in the Post-Restoration Year 4 assessment, and coarse gravel in both Post-Restoration Years 2 and 3 surveys, all coarser than the initial particle class determined by the Post-Restoration Year 1 survey, and recategorized for the first time the same as pre-restoration ratings. From the Post-Restoration Year 5 assessment, riffle feature median particle size significantly decreased, classifying as coarse gravel, while the meander feature and reachwide surveys remained stable in the very coarse gravel classification. Reachwide D_{84} decreased to medium gravel in 2017. The new crossover riffle at Station 1+10 had a D_{84} of very coarse gravel and the new meander bend/pool at Station 0+74.5 had a D_{84} of medium gravel. In the 2018 Post-Restoration study, the reachwide D_{84} increased to coarse gravel. The crossover riffle at Station 1+10 had an increased D_{84} to medium cobble and the meander bend/pool at Station 0+74.5 had an increased D_{84} to large cobble. In the 2019 Post-Restoration study, the reachwide D_{84} increased to small cobble. The D_{84} at the crossover riffle at Station 1+10 remained as medium cobble and the meander bend/pool at Station 0+74.5 had a decreased D_{84} to small cobble. In the 2020 Post-Restoration Year 4 study, the reachwide D_{84} remained as small cobble. The D_{84} at the crossover riffle coarsened to large cobble and the meander bend/pool had an increased D_{84} to medium cobble. In the 2022 Post-Restoration Year 5 study, the reachwide D_{84} remained as small cobble. The D_{84} at the crossover riffle significantly reduced to very coarse gravel and the meander bend/pool slightly declined to small cobble.

4.3 WC03

Pool and glide features have previously dominated reach WC03, as 65.6% and 67.5% of the reach was made up of pools and glides during Pre-Restoration Years 1 and 2, respectively. During Pre-Restoration Year 3, however, riffles and runs made up more than half (53.1%) of the reach (Table C-1). Pools and glides were dominant during Pre-Restoration Year 4 (58.5%). Changes in longitudinal profile were noted between the four years' of Pre-Restoration study, most notably the deepening of most pools reachwide between the first two years (Figure C-5). Pool depth has stayed consistent from Pre-Restoration Year 2 through Year 4 except for the pool feature at station 1+00 which has deepened about a foot.

In Post-Restoration Year 1 (2017), WC03 consisted of 66.0% riffle/run and 34% pool/glide which shows a large change from Pre-Restoration Year 4 (2015) when pools and glides were dominant. These percentages were similar in subsequent surveys, with the reach consisting of 62.7% riffle/run and 37.2% pool/glide in 2018 and 62.3% riffle/run and 37.7% pool/glide in 2019. In the Post-Restoration Year 4 survey, riffle/run to pool/glide distributions transitioned closer to Pre-Restoration distributions, consisting of 50.0% riffle/run and 50.0% pool/glide. In the Post-Restoration Year 5 survey, riffle/run to pool/glide distributions transitioned back to Years 1 through 3 Post-Restoration distributions, consisting of 66.1% riffle/run and 33.9% pool/glide. No instream restoration occurred on this reach and the stream had aggraded over time prior to 2018 (Figure C-5). Many of the pools became shallower due to this aggradation and some transitioned into riffles or runs altogether. Slight scouring was noted in this reach during the 2018 survey when compared to prior monitoring, mostly constrained to the upper 100 feet of the profile. This scouring was maintained from 2019 through 2022 and was evident throughout the reach instead of constrained to the upper 100 feet of the profile, likely due to above average rainfall between 2018 and 2022 which transported substrate out of the reach.

Cross-section 1 (Station 1+55) had been a crossover riffle when initially established during Pre-Restoration Year 1 of the study and again in Pre-Restoration Years 3 and 4. However, changes in channel profile resulted in the riffle feature migrating downstream, and this cross-section was within a pool feature when surveyed in Pre-Restoration Year 2 (Figure C-5). As a result, Year 2 bankfull cross-sectional dimensions changed significantly at this station, with the deepening of the channel bed (Table C-2). The Pre-Restoration Year 4 streambed most closely resembled that of the Pre-Restoration Year 2 study. The right streambank remained relatively unchanged at Cross-section 1 throughout the four-year Pre-Restoration study while the left bank slightly filled in between 2012 and 2015 (Figure C-15). Significant deepening also occurred at Cross-section 2 (Meander Bend at Station 2+07), and erosion of the outside (left) bank was also observed between Pre-Restoration Years 1 and 2 (Figure C-16). The left bank continued to erode between Pre-Restoration Years 2 and 3 while aggradation occurred in the stream bed near the left bank. Significant erosion continued on the left bank between Pre-Restoration Years 3 and 4 as well as scouring of the left bank streambed. Consequently, bankfull cross-sectional dimensions and entrenchment ratios also differed significantly at this station between all four Pre-Restoration years (Table C-2).

In the first year of Post-Restoration monitoring, Cross-section 1 at Station 1+56 continued eroding slightly on the left bank while the right bank aggraded around the toe of the bank almost 0.5 feet (Figure C-15). In 2018, the left bank stabilized, while scouring occurred around the toe of both the left and right banks. Erosion of the left bank was evident again during the 2019 survey while the toe of the left bank aggraded; measurements across the right bank demonstrated that it has remained stable. Erosion of the left bank was evident during the 2019 and 2020 surveys while the toe of the left bank aggraded in 2019 and remained similar in 2020; measurements across the right bank demonstrated that it has remained stable during Post-Restoration Years 1 through 3 surveys but aggraded approximately 0.33 feet in the Post-Restoration Year 4 survey. The Post-Restoration Year 5 survey of Cross-section 1 showed that both the right and left banks remained relatively stable but minimal scouring of 0.1-0.2 feet of sediment was noted across the entire channel. Cross-section 2 at Station 2+08 has undergone major changes since Pre-Restoration Year 4 (2015). The left bank has eroded an additional 4.0 to 6.5 feet from 2015 to 2022 and has undercut the bank; the left bank at Cross-section 2 eroded away enough between 2018 and 2019 to cause the left end pin of the cross-section to fall into the stream channel, making it necessary for the field crew to install a new end pin further up the bank (Figure C-16). The streambed at this cross-section continues to scour significantly on the left side of the channel and aggrade on the right side of the channel due to the encroaching point bar.

At Cross-section 1 (crossover riffle at Station 1+55), channel substrate became finer, with the D_{50} decreasing from very coarse gravel to coarse gravel between Pre-Restoration Years 1 and 3 (Table C-3). During Pre-Restoration Year 4, D_{50} increased and was once again categorized in the very coarse gravel size class. The D_{84} decreased from small cobble to very coarse gravel and back to small cobble over the four years of Pre-Restoration monitoring. In Post-Restoration Year 1, the D_{50} decreased to coarse gravel and the D_{84} remained very coarse gravel; the Post-Restoration Year 2 D_{50} remained coarse gravel and the D_{84} increased to small cobble. In Post-Restoration Year 3, the D_{50} increased to very coarse gravel and the D_{84} increased to small cobble; the Post-Restoration Year 4 D_{50} remained very coarse gravel and the D_{84} remained small cobble. In Post-Restoration Year 5, the D_{50} decreased to coarse gravel and the D_{84} decreased to very coarse gravel. This fluctuation over time in particle size demonstrates the variability of this portion of the reach due to sediments being transported through the reach from upstream erosion.

The D_{84} decreased at Cross-section 2 (Meander Bend at Station 2+07) from small cobble in Pre-Restoration Year 1 to very coarse gravel in Pre-Restoration Years 2 and 3 to coarse gravel in Pre-Restoration Year 4. At Cross-section 2, D_{50} particle size classes remained the same between the first two years of Pre-Restoration study (medium gravel) and increased during the third (coarse gravel). During the fourth Pre-Restoration year, D_{50} size decreased from coarse gravel to fine gravel. In Post-Restoration Years 1 and 2, the D_{50} increased to medium gravel and the D_{84} increased to very coarse gravel. In Post-Restoration Year 3, the D_{50} increased to coarse gravel and the D_{84} remained small cobble; the Post-Restoration Year 4 D_{50} decreased to medium gravel and the D_{84} decreased to very coarse gravel. In Post-Restoration Year 3, the D_{50} increased to coarse gravel and the D_{84} remained very coarse gravel.

Reachwide, the D_{50} was coarse gravel during three of the four Pre-Restoration study years with a slight increase to very coarse gravel occurring in Year 3. The D_{84} showed the same pattern as the D_{50}, increasing only during Pre-Restoration Year 3 to large cobble and remaining in the same small cobble class Pre-Restoration Years 1, 2, and 4. During the first Post-Restoration year (2017), the reachwide D_{50} was medium gravel and D_{84} was very coarse gravel; reachwide D_{50} increased to coarse gravel in 2018, and D_{84} remained very coarse gravel, continuing the trend to smaller material than in years past. The reachwide D_{50} remained as coarse gravel in 2019, and D_{84} increased to small cobble, discontinuing the trend to smaller materials from years past. The reachwide D_{50} remained as coarse gravel and D_{84} remained small cobble in 2020; reachwide D_{50} remained as coarse gravel and D_{84} decreased to very coarse gravel in 2022. Post-restoration particle sizes seem to be leveling out over time throughout this reach, though smaller than seen in pre-restoration conditions; future monitoring is needed to determine if the particle size distribution is stabilizing in this reach, or if continued erosion will result in shifting particle size distributions throughout this reach.

4.4 WC04

No significant changes were observed in the profile of the downstream portion of the reach at site WC04 between the four years of Pre-Restoration study. However, during Pre-Restoration Years 2 through 4 surveys and the Post-Restoration Year 1 survey, the stream channel was dry from above the pool feature at Station 1+80 to the top of the reach at Station 3+00 and beyond; the streambed was found to be mostly dry from Station 2+50 to the top of the reach in the Post-Restoration Year 2 survey. Around this same station and above, channel aggradation can be seen when comparing the profiles of the initial year and all the following years' surveys (Figure C-6) which may explain the decrease in water depth between these surveys. While no significant channel alterations were noted during the Post-Restoration Years 3 and 4 surveys, this reach was found to have water throughout the entire longitudinal profile both years. In Post-Restoration year 5, the reach was found to be largely dry above Station 2+50, mirroring conditions seen in the Post-Restoration Year 2 survey. Reach length, slope, and proportion of features within the reach remained relatively unchanged (Table C-1).

Similar to the profile, the cross-sections within this reach also remained relatively unchanged between the first three years of Pre-Restoration study, with the exception of some lower bank erosion observed at Cross-section 1 (Meander at Station 1+08) between Pre-Restoration Years 1 through 3 (Figure C-17). During Pre-Restoration Year 4, erosion on the lower left bank continued and was more apparent resulting in higher bankfull and width depth dimensions. This station was identified as a riffle located just above the top of a pool during the initial year of Pre-Restoration monitoring, but was within part of the pool when surveyed in all other subsequent Pre-Restoration years. The channel was actively widening and cutting into the bank at this station during the Pre-Restoration Year 4 survey, resulting in changes in cross-sectional dimensions. This undercutting continued to take place in Post-Restoration Years 1 through 4 (Table C-2). The overall top of bank area slightly decreased again in 2019, remained very similar in 2020, and more significantly decreased again in 2022, due to the growing point bar and bench, while bankfull area slightly increased from the 2018 survey (Figure C-17). Cross-section 1 at Station 1+10 is now in a meander pool feature in Post-Restoration Years 1 through 5, a change from the original riffle feature in Pre-Restoration Year 1 and the pool feature in Pre-Restoration Years 2 through 4 (Table C-2). Cross-section 2 at Station 1+68 remains unchanged and stable through Post-Restoration Year 4, with slight aggradation occurring on the right side of the channel in Post-Restoration Years 1 and 2 (Figure C-18). Changes at Cross-section 2 were noted in 2022, with measured increases in both bankfull width and bankfull cross-sectional area; these increases were attributed to slight erosion of the left bank. Future studies will determine if this bank erosion continues and its effect on stream channel form at this cross-section.

Reachwide D_{84} particle size classes remained the same during all four Pre-Restoration years (small cobble), decreased in Post-Restoration Years 1 and 2 to very coarse gravel, increased back to small cobble in Post-Restoration Years 3 and 4, and decreased back to very coarse gravel in Post Restoration Year 5 (Table C-3). D_{84} remained the same at Cross-section 1 during the first three years of Pre-Restoration study (small cobble) and decreased during the fourth year to coarse gravel, where it remained in Post-Restoration Year 1. An increase in D_{84} to very coarse gravel was noted at Cross-section 1 in 2018, and but returned to coarse gravel in 2019. D_{84} at Cross-section 1 in 2020 coarsened again to very coarse gravel and remained in this classification in 2022. At Cross-section 2, D_{84} decreased from small cobble to very coarse gravel between Pre-Restoration Years 2 and 3. It increased back to small cobble between Pre-Restoration Years 3 and 4 and had remained small cobble through Post-Restoration Year 3. D_{84} increased from small cobble to medium cobble between Post-Restoration Years 3 and 4 and decreased in particle size back to very coarse gravel in Post-Restoration Year 5 (Table C-3).

Reachwide D_{50} particle size class increased from coarse gravel to very coarse gravel between Pre-Restoration Years 2 and 3 and decreased back to coarse gravel during Pre-Restoration Year 4 for the reachwide survey. During the Post-Restoration Year 1 survey, the reachwide D_{50} slightly decreased to medium gravel, but increased back to coarse gravel in the 2018 through 2020 studies (Table C-3). In 2022, median particle size decreased back to medium gravel reachwide. Cross-section 1 D_{50} has fluctuated by decreasing from medium gravel to very coarse sand and again increasing to medium gravel and Cross-section 2 remained the same (very coarse gravel) between Pre-Restoration Years 2, 3, and 4. In Post-Restoration Year 1, the D_{50} at Cross-section 1 remained medium gravel while the D_{50} at Cross-section 2 decreased to coarse gravel. Post-Restoration Year 2 results showed that the D_{50} at Cross-section 1 decreased again to very coarse sand while the D_{50} at Cross-section 2 increased back to very coarse gravel. Post-Restoration Year 3 results showed that the D_{50} at Cross-section 1 remained as very coarse sand while the D_{50} at Cross-section 2 decreased to coarse gravel. The Post-Restoration Year 4 assessment found the D_{50} at Cross-section 1 decreased to coarse sand, while the D_{50} at Cross-section 2 coarsened to very coarse gravel. The Post-Restoration Year 5 assessment found the D_{50} at Cross-section 1 coarsened substantially to medium gravel, while the D_{50} at Cross-section 2 decreased particle size back to coarse gravel (Table C-3).

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5.0 CONCLUSIONS

The data presented herein provide an assessment of geomorphic conditions within the Wheel Creek watershed prior to and following completion of restoration efforts. During the Pre-Restoration Years 1 and 2 studies, none of the planned restoration projects had been completed within this watershed. During the Pre-Restoration Year 3 study, two planned restoration projects had been constructed while the remaining projects were still in planning stages. Continued planning occurred during Pre-Restoration Year 4 but no new construction activities were initiated. Restoration activities were all completed as of the Post-Restoration Year 1 survey; thus the 2022 survey is the fifth annual assessment following completion of restoration. Results of the geomorphic monitoring show that bank erosion continues to be prevalent in the two reaches (WC03, WC04) that did not receive stream restoration, but has improved in those reaches where instream channel restoration activities took place (WC01, WC02). Erosion of stream banks not only increases the sediment supply to the watershed but also provides a potential source of nutrients, especially phosphorus. Stream bank erosion is a common symptom of streams like those in Wheel Creek, where urban land cover is dominant (46.1%), contributing large amounts of impervious cover (21.4%) to the watershed (Becker, 2011). Efforts have been made to decrease the impact of damaging storm water flow causing erosion among the unstable banks. The two reaches that were restored (WC01, WC02) have stable, vegetated banks in each post-restoration survey and improved floodplain access in some areas but are still somewhat entrenched in others. In both restored reaches, surveyed cross-sections exhibited aggradation in the five years following completion of restoration; the undermining and failure of the bank armoring at station WC01 Cross-section 2 found in 2020 compromised the stability of the bank and effectiveness of the restoration, as portions of the armoring were found to have slumped and fallen into the stream during the 2022 survey; restoration repair efforts are scheduled. These streams may continue to adjust in the coming years, especially during high flow events. Future Post-Restoration monitoring will enable assessment of their stability and the effects of the restoration activities that occurred.

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6.0 REFERENCES

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APPENDIX A

PHOTOS

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WC01 – Facing downstream at Station 4+50

WC01 - Facing downstream at Station 3+00

WC01 – Facing downstream at Station 2+00

WC01 – Facing downstream at Station 1+00

WC01 – Facing upstream from Station 0+00

WC02 – Facing downstream at Station 3+00

WC02 – Facing downstream at Station 2+00

WC02 – Facing downstream at Station 1+00

WC02 – Facing downstream at Station 0+50

WC02 – Facing upstream at Station 0+00

WC03 – Facing downstream at Station 3+08

WC03 – Facing downstream at Station 2+50

WC03 – Facing downstream at Station 1+50

WC03 – Facing downstream at Station 0+50

WC03 – Facing upstream at Station 0+00

WC04 – Facing downstream at Station 3+00

WC04 – Facing downstream at Station 2+00

WC04 – Facing downstream at Station 1+00

WC04 – Facing downstream at Station 0+50

WC04 – Facing upstream at Station 0+00

WC01 – XS-1 facing upstream

WC01 – XS-1 facing downstream

WC01 – XS-1 facing right bank

WC01 – XS-1 facing left bank

WC01 – XS-2 facing upstream

WC01 – XS-2 facing downstream

WC01 – XS-2 facing right bank

WC01 – XS-2 facing left bank

WC02 – XS-1 facing upstream

WC02 – XS-1 facing downstream

WC02 – XS-1 facing right bank

WC02 – XS-1 facing left bank

WC02 – XS-2 facing upstream

WC02 – XS-2 facing downstream

WC02 – XS-2 facing right bank

WC02 – XS-2 facing left bank

WC03 – XS-1 facing upstream

WC03 – XS-1 facing downstream

WC03 – XS-1 facing right bank

WC03 – XS-1 facing left bank

WC03 – XS-2 facing upstream

WC03 – XS-2 facing downstream

WC03 – XS-2 facing right bank

WC03 – XS-2 facing left bank

WC04 – XS-1 facing upstream

WC04 – XS-1 facing downstream

WC04 – XS-1 facing right bank

WC04 – XS-1 facing left bank

WC04 – XS-2 facing upstream

WC04 – XS-2 facing downstream

WC04– XS-2 facing right bank

WC04 – XS-2 facing left bank

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APPENDIX B

GEOMORPHIC ASSESSMENT DATA

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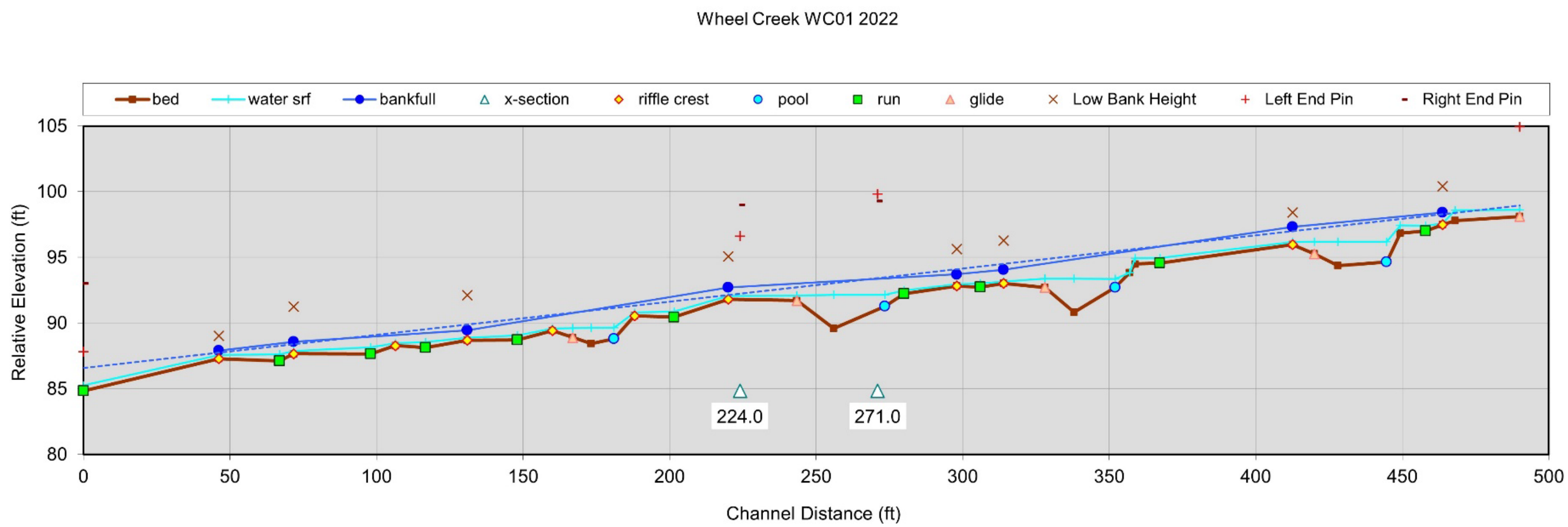
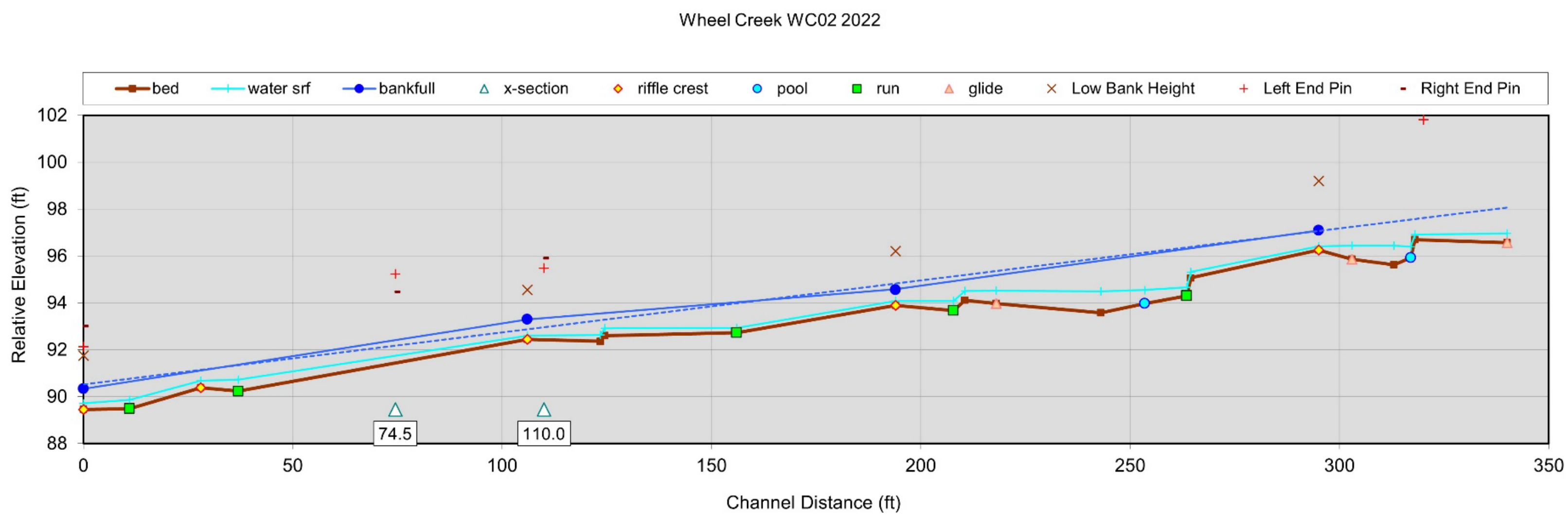
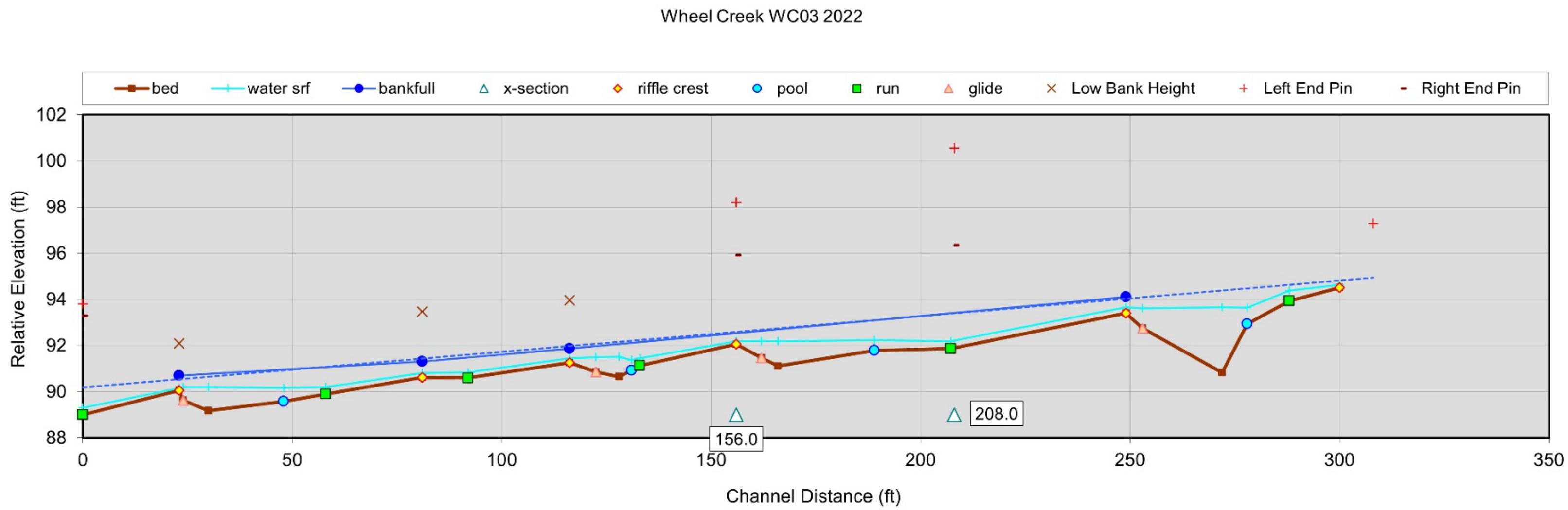
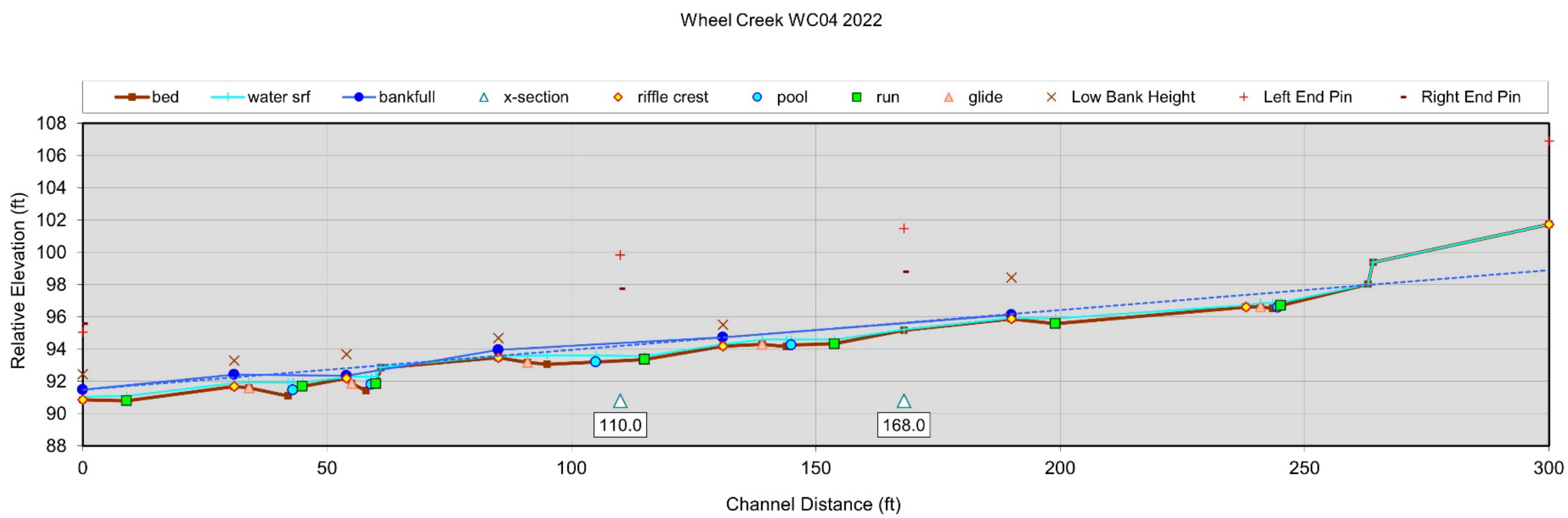

Wheel Creek WC01 2022
bed
water srf
bankfull
x-section
riffle crest
pool
run
glide
Low Bank Height
Left End Pin
Right End Pin
Relative Elevation (ft)
Channel Distance (ft)
224.0
271.0

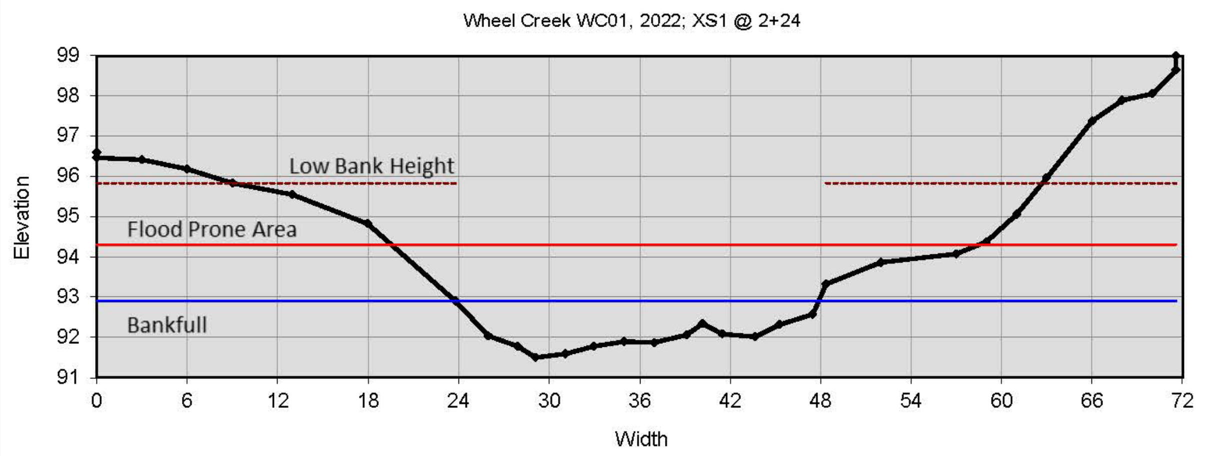

Wheel Creek WC02 2022
bed
water srf
bankfull
x-section
riffle crest
pool
run
glide
Low Bank Height
Left End Pin
Right End Pin
Relative Elevation (ft)
Channel Distance (ft)
74.5
110.0



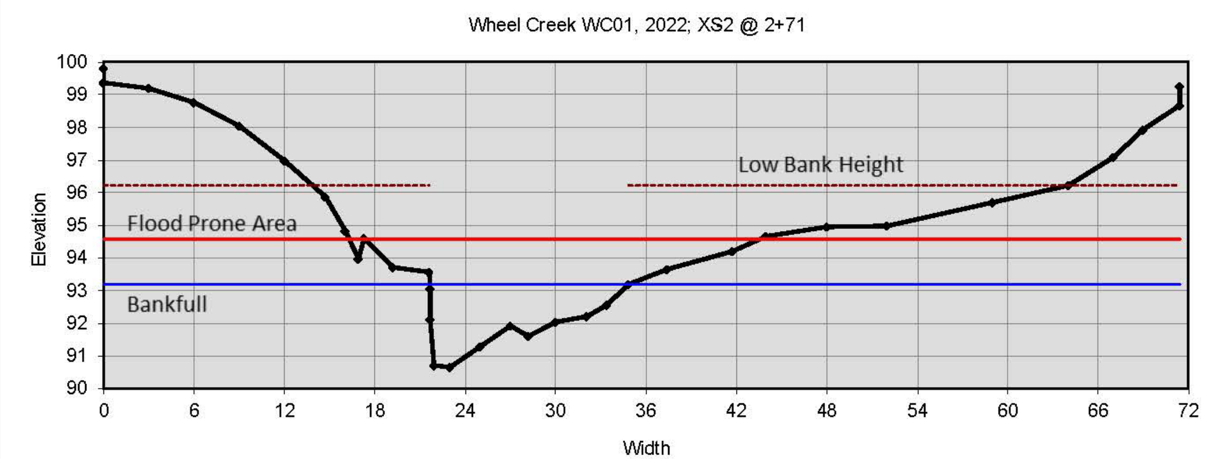
Wheel Creek WC03 2022
bed
water srf
bankfull
x-section
riffle crest
pool
run
glide
Low Bank Height
Left End Pin
Right End Pin
Relative Elevation (ft)
Channel Distance (ft)
156.0
208.0



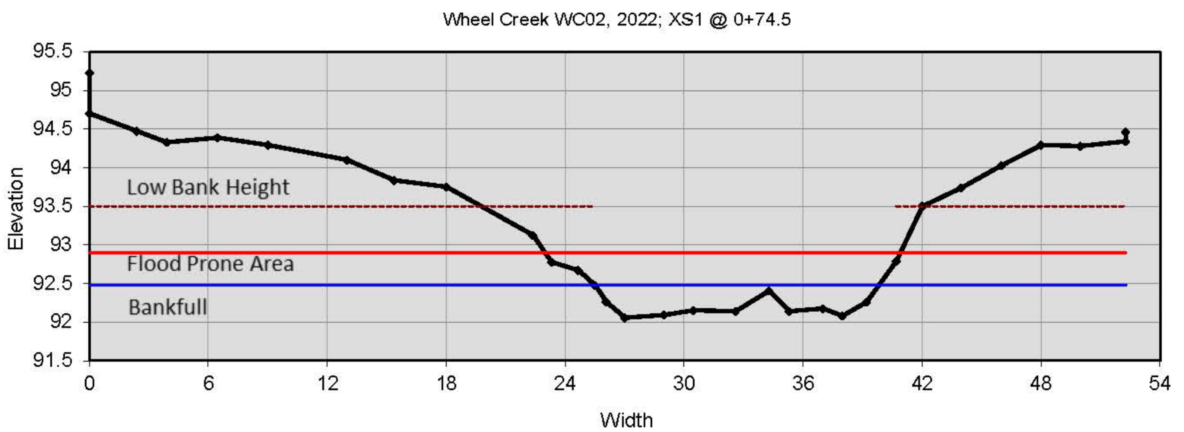
Wheel Creek WC04 2022
bed
water srf
bankfull
x-section
riffle crest
pool
run
glide
Low Bank Height
Left End Pin
Right End Pin
Relative Elevation (ft)
Channel Distance (ft)
110.0
168.0



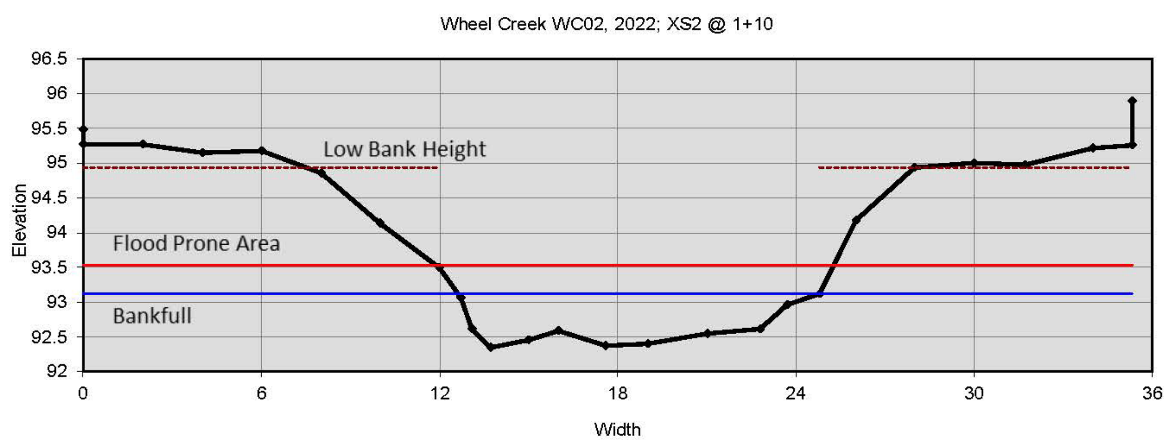
Bankfull Dimensions		Flood Dimensions		Materials	
21.4	x-section area (ft.sq.)	39.0	W flood prone area (ft)	83	D50 Riffle (mm)
24.1	width (ft)	1.6	entrenchment ratio	170	D84 Riffle (mm)
0.9	mean depth (ft)	4.3	low bank height (ft)	52	threshold grain size (mm):
1.4	max depth (ft)	3.1	low bank height ratio		
24.6	wetted parimeter (ft)				
0.9	hyd radi (ft)				
27.1	width-depth ratio				



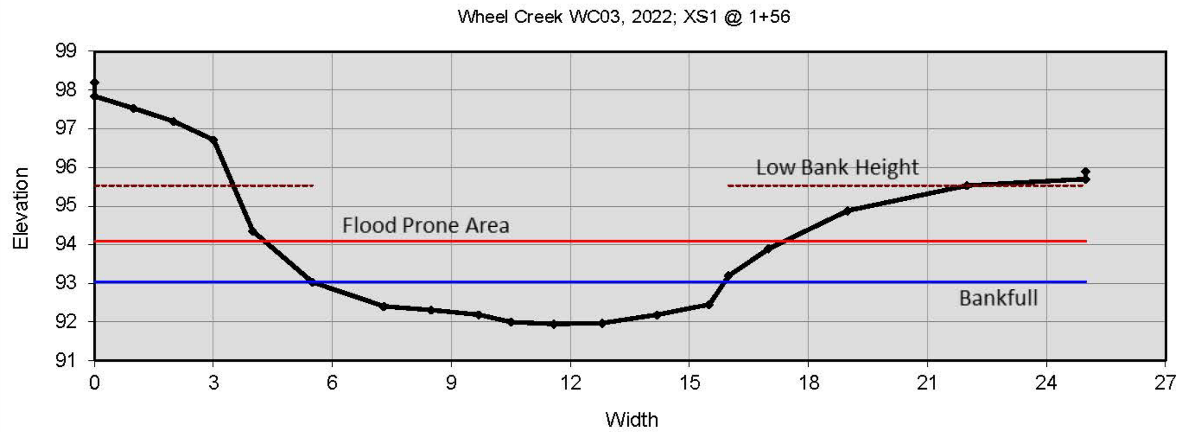
Bankfull Dimensions		Flood Dimensions		Materials	
18.5	x-section area (ft.sq.)	27.2	W flood prone area (ft)	83	D50 Riffle (mm)
13.1	width (ft)	2.1	entrenchment ratio	170	D84 Riffle (mm)
1.4	mean depth (ft)	5.6	low bank height (ft)	42	threshold grain size (mm):
2.5	max depth (ft)	2.2	low bank height ratio		
15.9	wetted parimeter (ft)				
1.2	hyd radi (ft)				
9.3	width-depth ratio				



Bankfull Dimensions		Flood Dimensions		Materials	
4.3	x-section area (ft.sq.)	17.9	W flood prone area (ft)	28	D50 Riffle (mm)
14.3	width (ft)	1.3	entrenchment ratio	61	D84 Riffle (mm)
0.3	mean depth (ft)	1.4	low bank height (ft)	22	threshold grain size (mm):
0.4	max depth (ft)	3.4	low bank height ratio		
14.5	wetted parimeter (ft)				
0.3	hyd radi (ft)				
47.8	width-depth ratio				



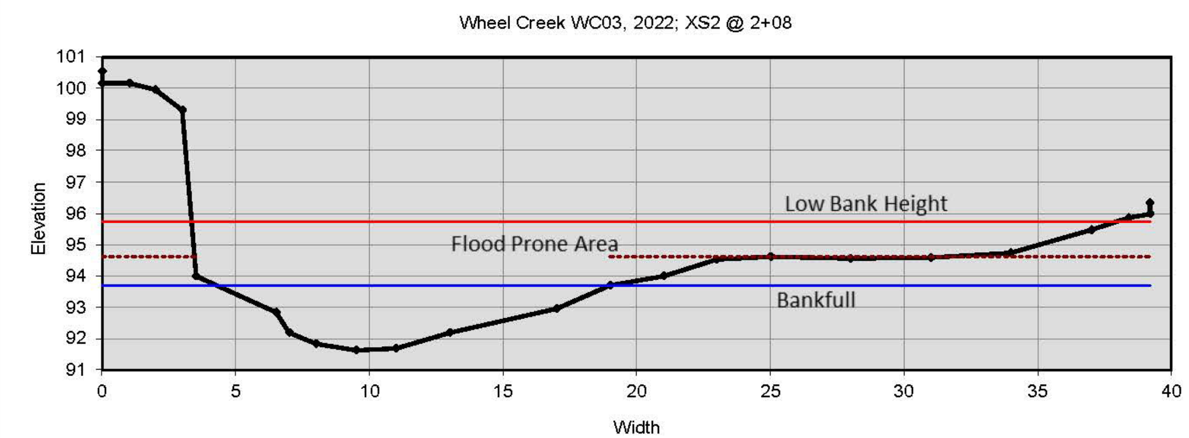
Bankfull Dimensions		Flood Dimensions		Materials	
6.8	x-section area (ft.sq.)	13.4	W flood prone area (ft)	28	D50 Riffle (mm)
12.2	width (ft)	1.1	entrenchment ratio	61	D84 Riffle (mm)
0.6	mean depth (ft)	2.6	low bank height (ft)	28	threshold grain size (mm):
0.8	max depth (ft)	3.4	low bank height ratio		
12.6	wetted parimeter (ft)				
0.5	hyd radi (ft)				
22.0	width-depth ratio				



Bankfull Dimensions	
7.8	x-section area (ft.sq.)
10.4	width (ft)
0.7	mean depth (ft)
1.1	max depth (ft)
10.9	wetted parimeter (ft)
0.7	hyd radi (ft)
13.9	width-depth ratio

Flood Dimensions	
13.1	W flood prone area (ft)
1.3	entrenchment ratio
3.6	low bank height (ft)
3.3	low bank height ratio

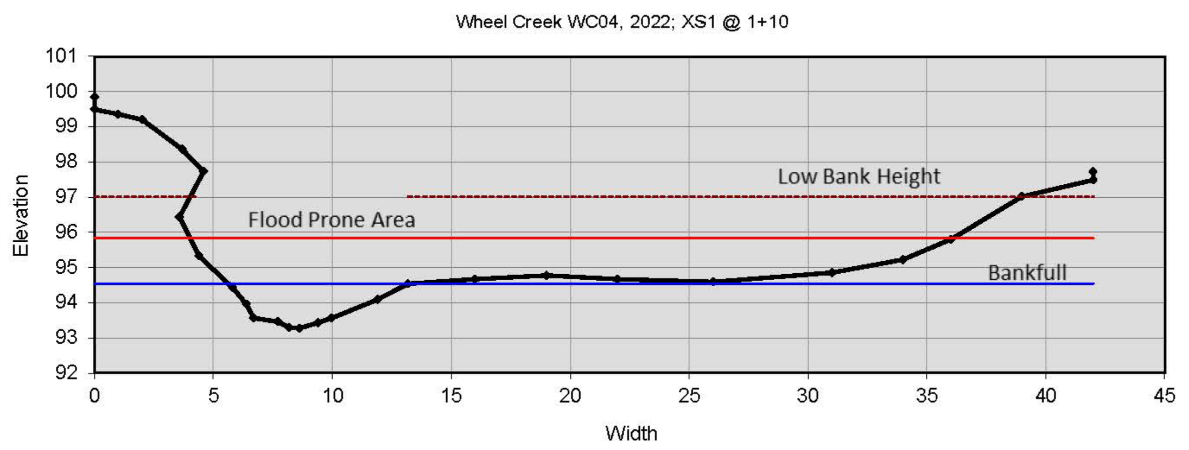
Materials	
28	D50 Riffle (mm)
61	D84 Riffle (mm)
37	threshold grain size (mm):



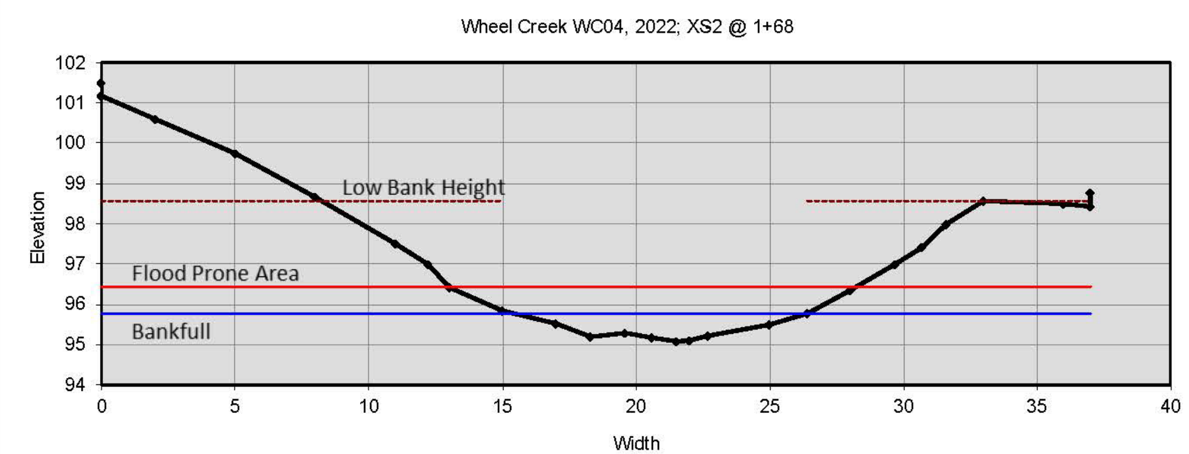
Bankfull Dimensions	
17.9	x-section area (ft.sq.)
14.7	width (ft)
1.2	mean depth (ft)
2.1	max depth (ft)
15.5	wetted parimeter (ft)
1.2	hyd radi (ft)
12.1	width-depth ratio

Flood Dimensions	
34.7	W flood prone area (ft)
2.4	entrenchment ratio
3.0	low bank height (ft)
1.5	low bank height ratio

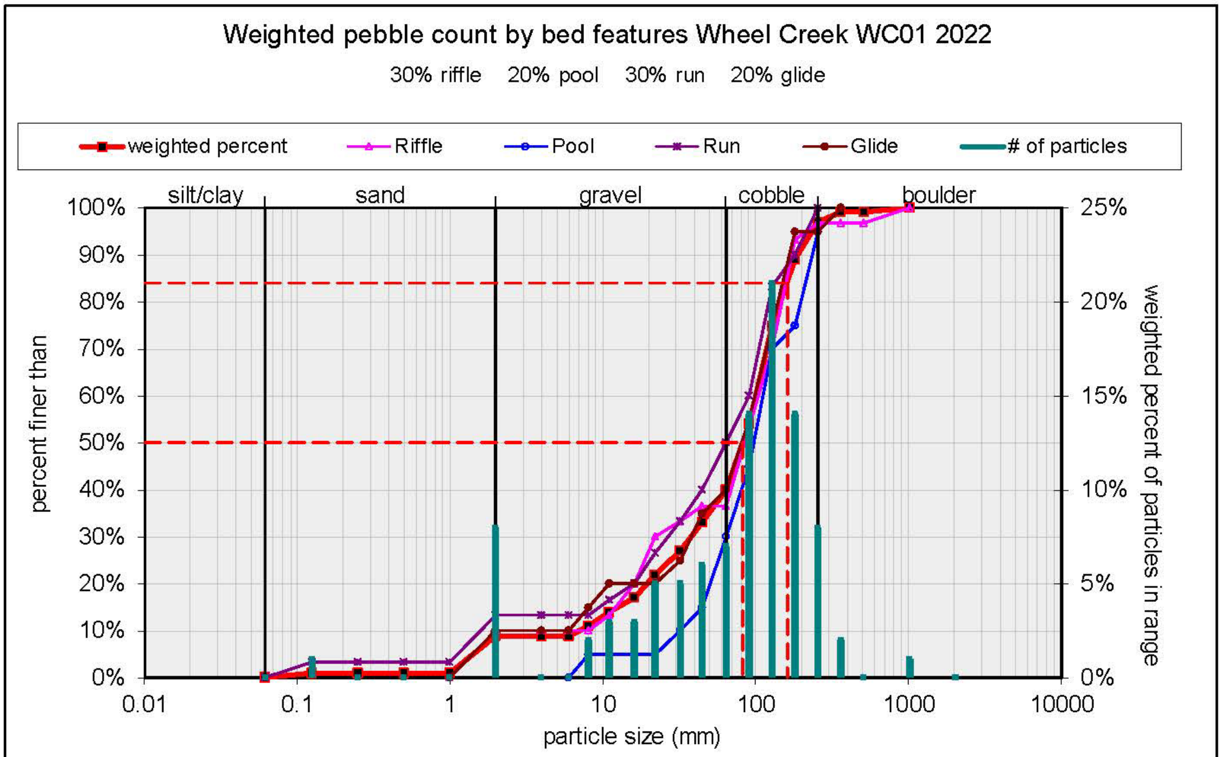
Materials	
28	D50 Riffle (mm)
61	D84 Riffle (mm)
60	threshold grain size (mm):



Bankfull Dimensions		Flood Dimensions		Materials	
5.8	x-section area (ft.sq.)	32.0	W flood prone area (ft)	15	D50 Bed (mm)
7.6	width (ft)	4.2	entrenchment ratio	58	D84 Bed (mm)
0.8	mean depth (ft)	3.8	low bank height (ft)	33	threshold grain size (mm):
1.3	max depth (ft)	2.9	low bank height ratio		
8.2	wetted parimeter (ft)				
0.7	hyd radi (ft)				
9.9	width-depth ratio				



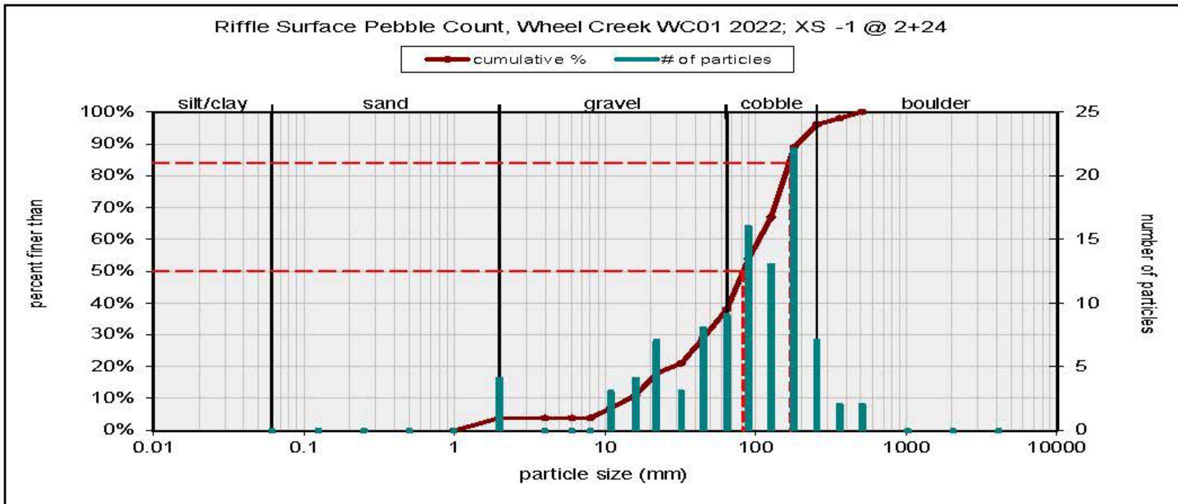
Bankfull Dimensions		Flood Dimensions		Materials	
4.4	x-section area (ft.sq.)	15.3	W flood prone area (ft)	15	D50 Bed (mm)
11.0	width (ft)	1.4	entrenchment ratio	58	D84 Bed (mm)
0.4	mean depth (ft)	3.5	low bank height (ft)	28	threshold grain size (mm):
0.7	max depth (ft)	5.1	low bank height ratio		
11.1	wetted parimeter (ft)				
0.4	hyd radi (ft)				
27.1	width-depth ratio				



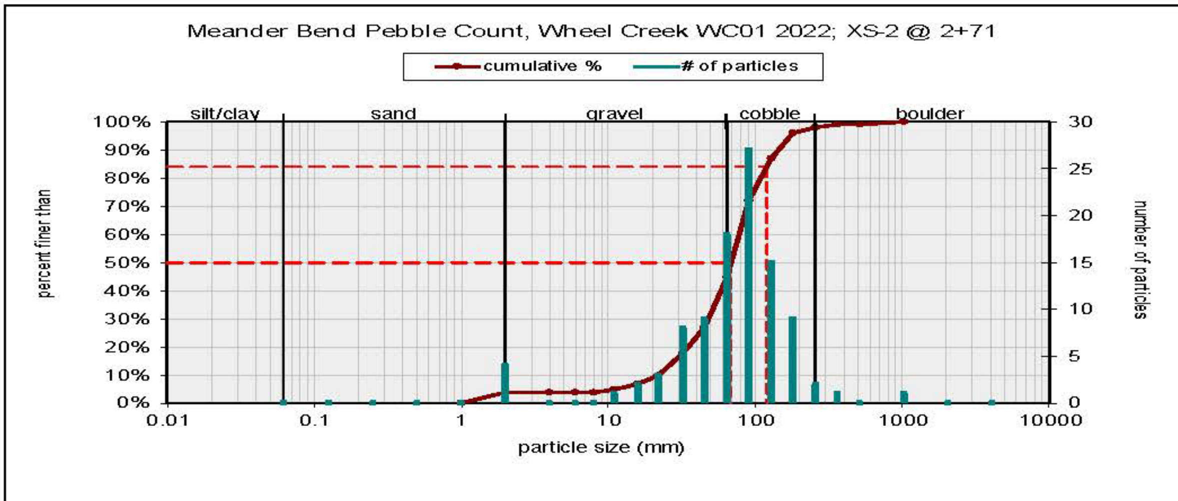
Size (mm)	
D16	14
D35	50
D50	82
D65	110
D84	160
D95	230

Size Distribution	
mean	47.3
dispersion	3.9
skewness	-0.23

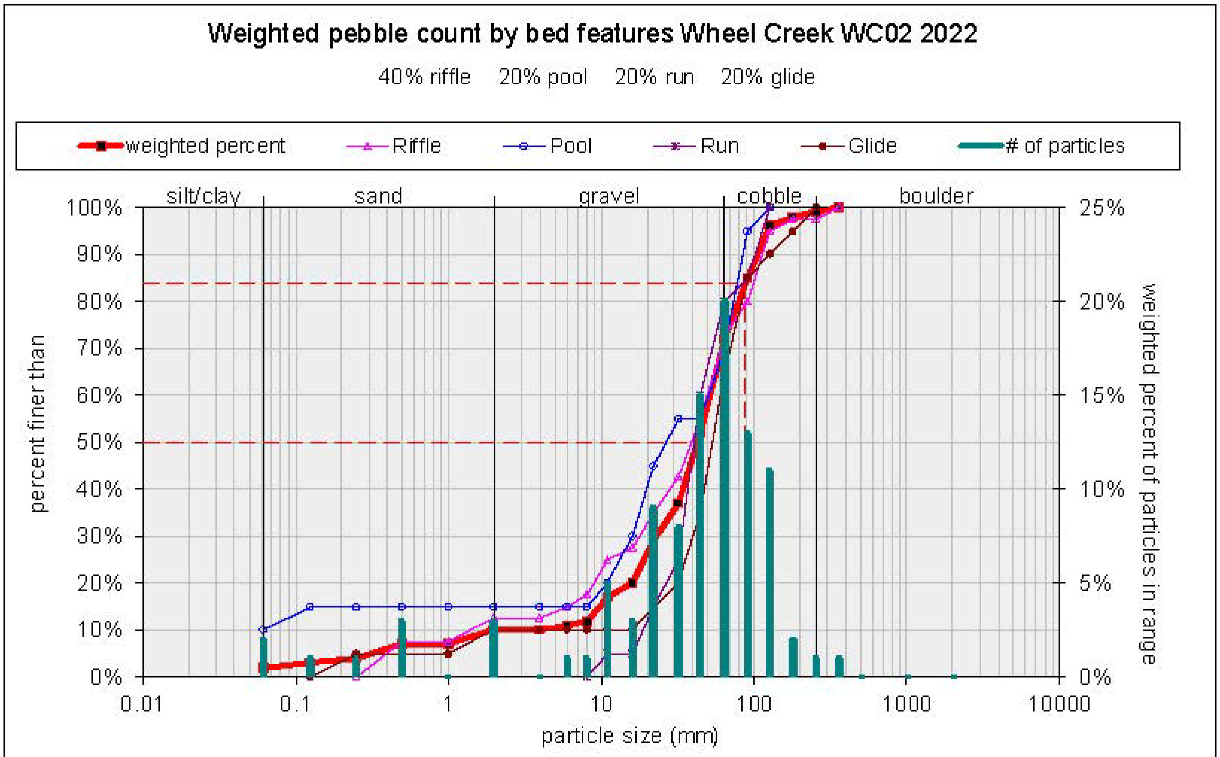
Type	
silt/clay	0%
sand	9%
gravel	31%
cobble	57%
boulder	3%



Size (mm)		Size Distribution		Type	
D16	20	mean	58.3	silt/clay	0%
D35	57	dispersion	3.1	sand	4%
D50	83	skewness	-0.16	gravel	34%
D65	120			cobble	58%
D84	170			boulder	4%
D95	240				



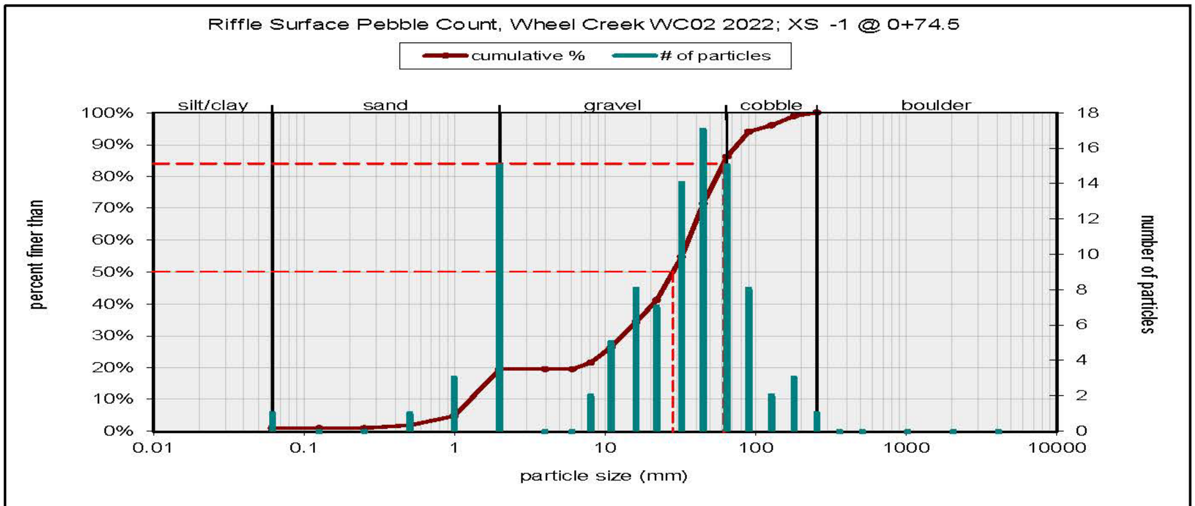
Size (mm)			Size Distribution		Type	
D16	29	3.4	mean	59.0	silt/clay	0%
D35	53	12	dispersion	2.1	sand	4%
D50	68	17	skewness	-0.08	gravel	41%
D65	82	20			cobble	53%
D84	120	29			boulder	2%
D95	170	39				



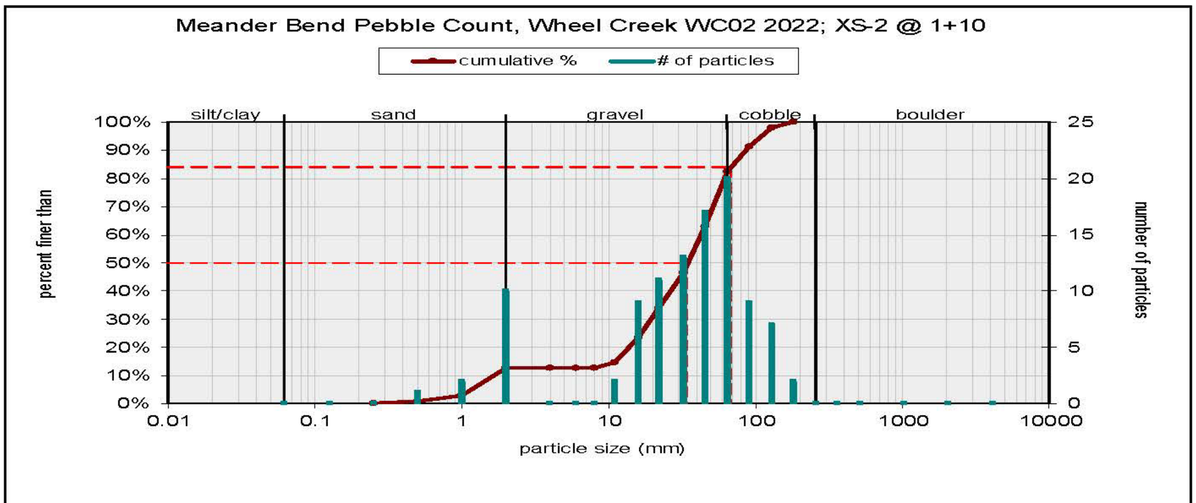
Size (mm)	
D16	10
D35	29
D50	43
D65	57
D84	88
D95	120

Size Distribution	
mean	29.7
dispersion	3.2
skewness	-0.17

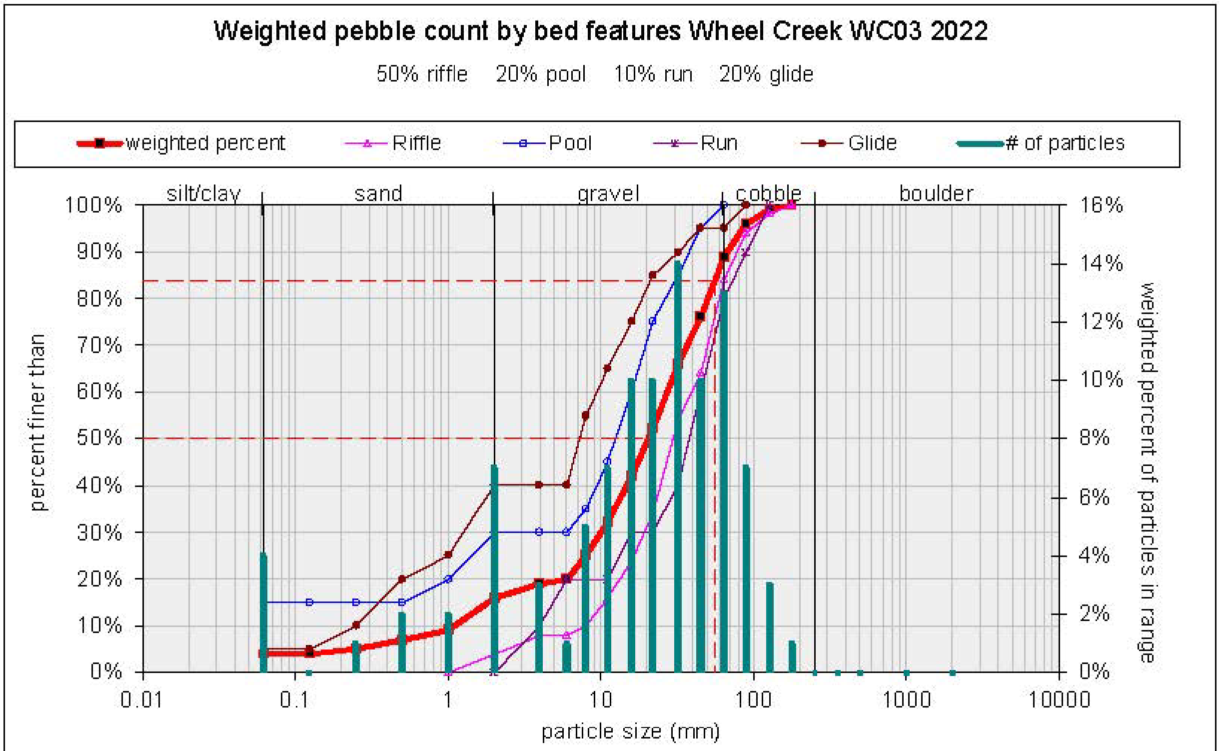
Type	
silt/clay	2%
sand	8%
gravel	62%
cobble	27%
boulder	1%



Size (mm)		Size Distribution		Type	
D16	1.7	mean	10.2	silt/clay	1%
D35	17	dispersion	9.3	sand	19%
D50	28	skewness	-0.35	gravel	67%
D65	39			cobble	14%
D84	61			boulder	0%
D95	110				



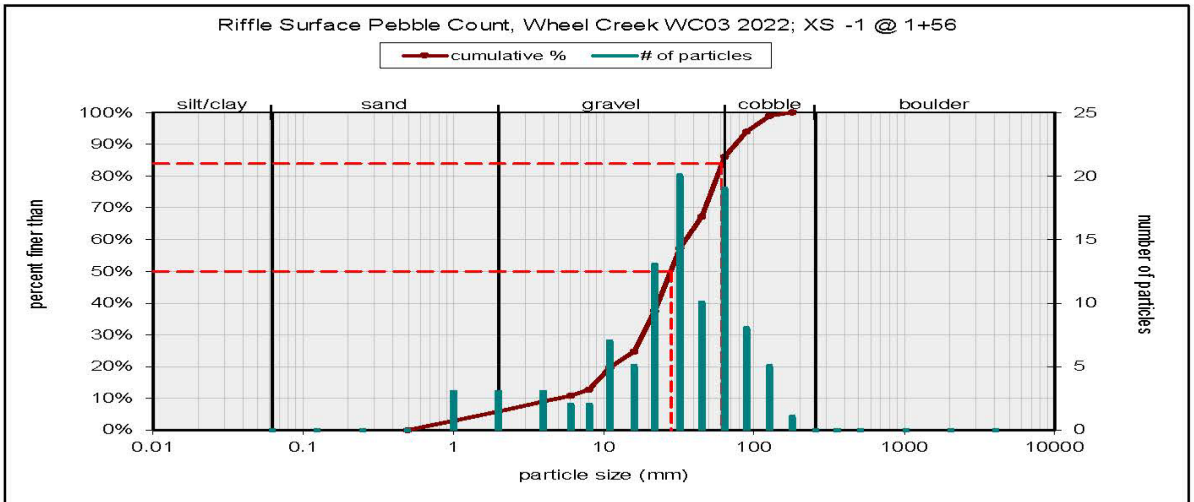
Size (mm)			Size Distribution		Type	
D16	12	3.4	mean	28.6	silt/clay	0%
D35	23	12	dispersion	2.4	sand	13%
D50	34	17	skewness	-0.09	gravel	70%
D65	47	20			cobble	17%
D84	68	29			boulder	0%
D95	110	39				



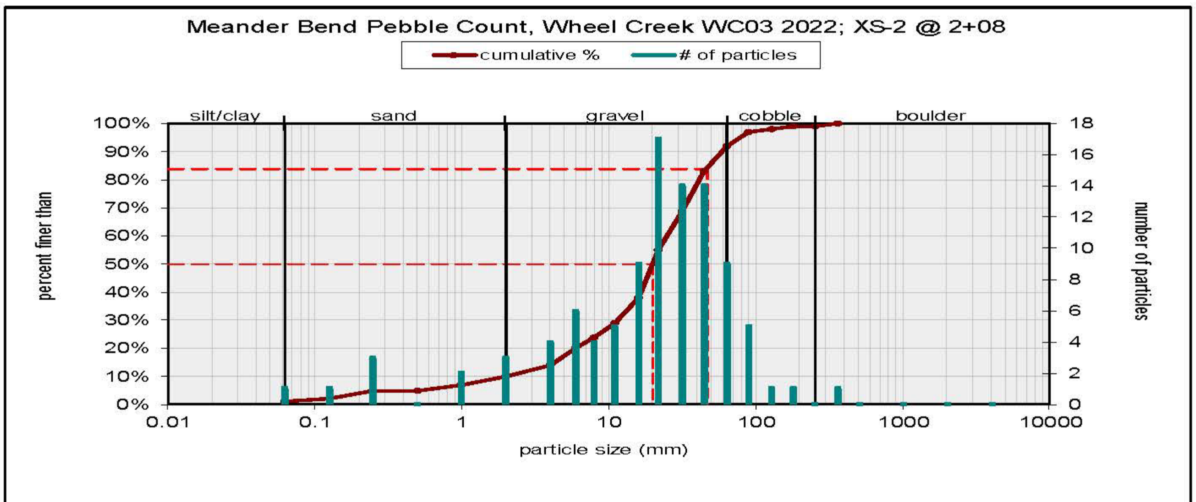
Size (mm)	
D16	2
D35	12
D50	21
D65	31
D84	56
D95	86

Size Distribution	
mean	10.6
dispersion	6.6
skewness	-0.25

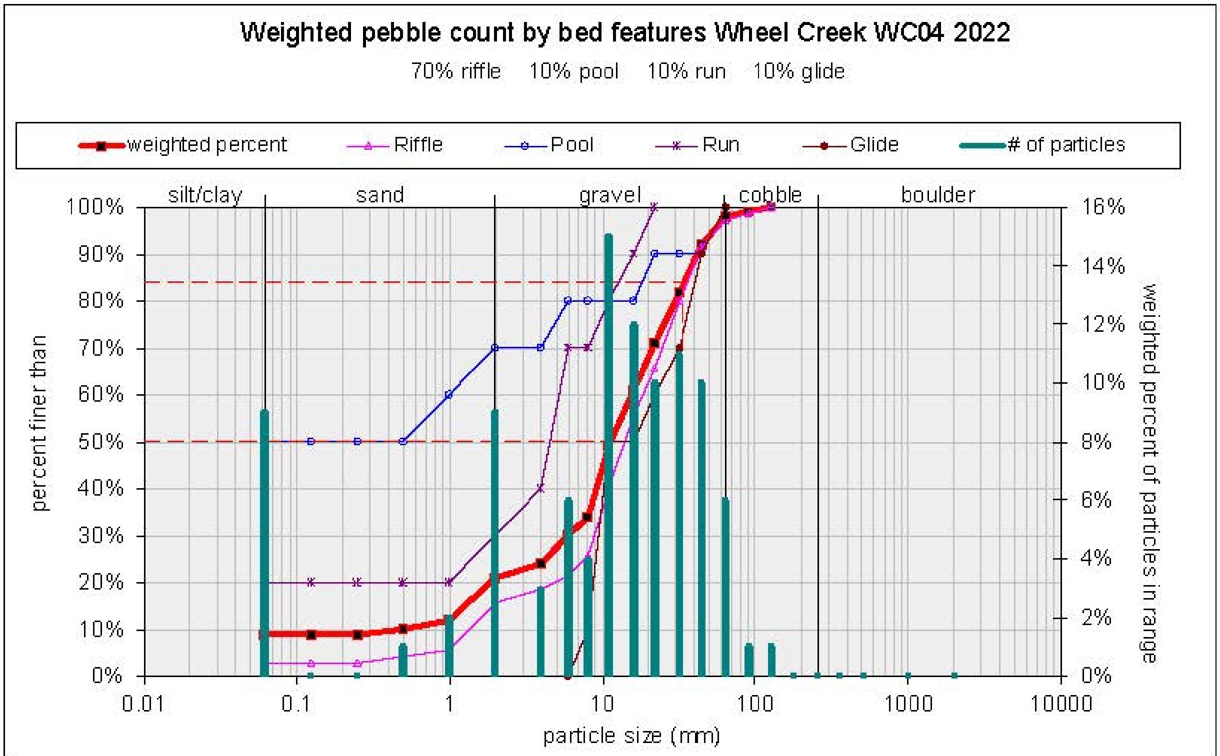
Type	
silt/clay	4%
sand	12%
gravel	73%
cobble	11%
boulder	0%



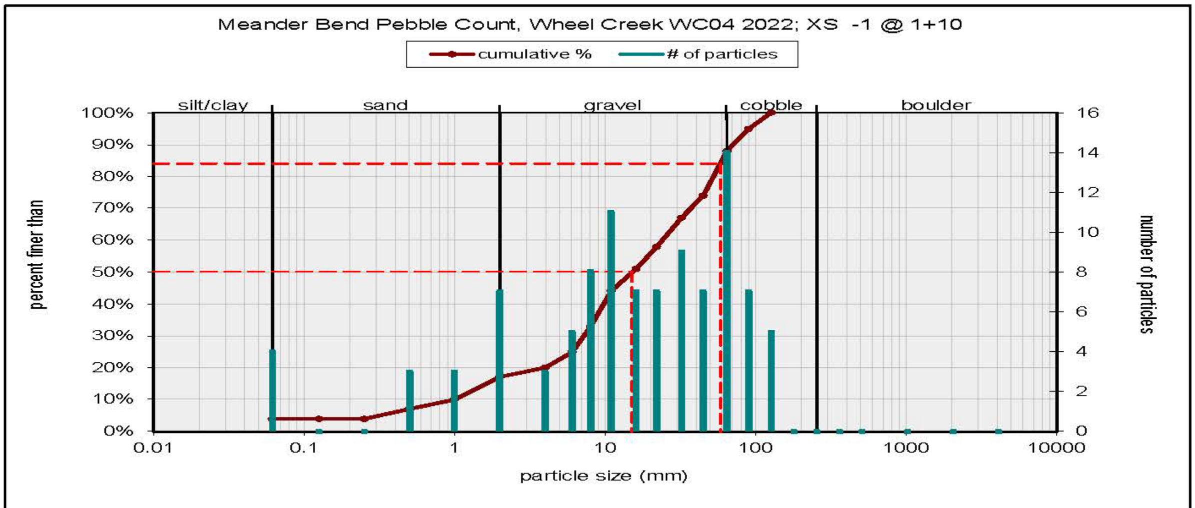
Size (mm)		Size Distribution		Type	
D16	9.2	mean	23.7	silt/clay	0%
D35	21	dispersion	2.6	sand	6%
D50	28	skewness	-0.08	gravel	80%
D65	42			cobble	14%
D84	61			boulder	0%
D95	96				



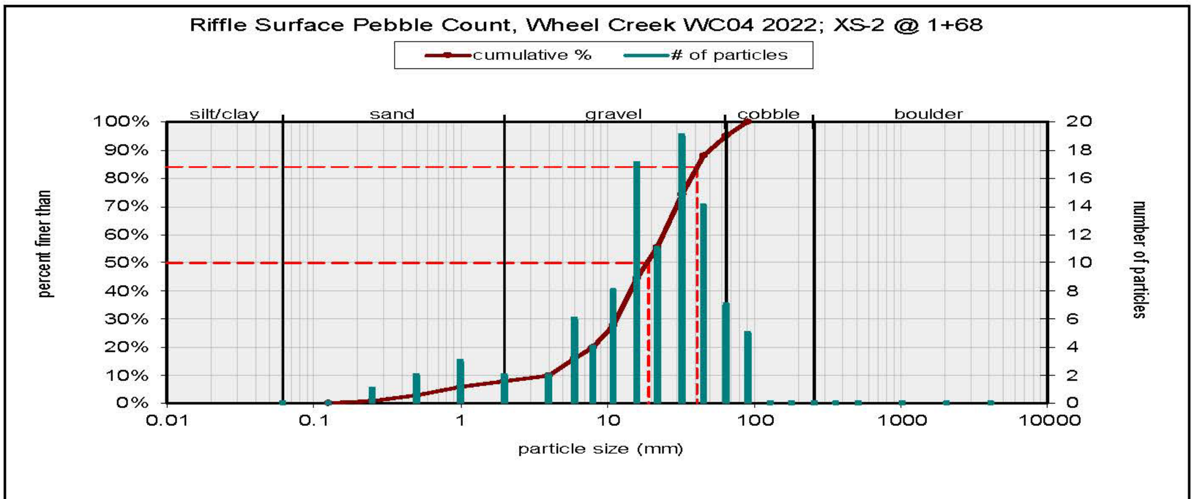
Size (mm)			Size Distribution		Type	
D16	4.6	3.4	mean	14.7	silt/clay	1%
D35	14	12	dispersion	3.3	sand	9%
D50	20	17	skewness	-0.13	gravel	82%
D65	29	20			cobble	7%
D84	47	29			boulder	1%
D95	79	39				



Size (mm)		Size Distribution		Type	
D16	1.4	mean	6.9	silt/clay	9%
D35	8.2	dispersion	5.5	sand	12%
D50	11	skewness	-0.17	gravel	77%
D65	18			cobble	2%
D84	34			boulder	0%
D95	54				



Size (mm)		Size Distribution		Type	
D16	1.8	mean	10.2	silt/clay	4%
D35	8.5	dispersion	6.1	sand	13%
D50	15	skewness	-0.14	gravel	71%
D65	29			cobble	12%
D84	58			boulder	0%
D95	90				



Size (mm)			Size Distribution		Type	
D16	6.1	3.4	mean	15.8	silt/clay	0%
D35	13	12	dispersion	2.6	sand	8%
D50	19	17	skewness	-0.09	gravel	87%
D65	27	20			cobble	5%
D84	41	29			boulder	0%
D95	64	39				

APPENDIX C

ANNUAL COMPARISONS

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Table C-1. Comparisons of Longitudinal Profile Survey Pre-Restoration Year 1 – Year 4 (2010-2015) and Post-Restoration Years 1 – 5 (2017-2022)

Reach	Year	Length (ft)	Slope	Proportion of Features			
				Riffle	Run	Pool	Glide
WC01*	2010	400	2.3%	43.6%	11.3%	22.1%	23.0%
	2012	420	2.2%	54.6%	7.3%	29.2%	8.9%
	2013	420	2.2%	55.7%	8.2%	23.8%	12.3%
	2015	420	2.2%	50.9%	24.8%	14.1%	10.2%
	2017	*490*	*2.6%*	*47.5%*	*7.6%*	*36.6%*	*8.3%*
	2018	*490*	*2.7%*	*48.5%*	*8.6%*	*28.6%*	*14.4%*
	2019	*490*	*2.7%*	*46.6%*	*12.7%*	*29.4%*	*11.3%*
	2020	*490*	*2.7%*	*35.6%*	*17.2%*	*27.8%*	*19.4%*
	2022	*490*	*2.7%*	*38.4%*	*26.8%*	*18.9%*	*15.9%*
WC02*	2010	350	2.3%	53.4%	0%	46.6%	0%
	2012	350	2.4%	33.7%	11.0%	38.6%	16.7%
	2013	350	2.3%	48.1%	12.6%	26.3%	13.0%
	2015	350	2.2%	49.4%	25.1%	13.4%	12.1%
	2017	*321.5*	*2.3%*	*57.3%*	*6.3%*	*28.5%*	*10.5%*
	2018	*320*	*2.3%*	*45.0%*	*15.3%*	*28.1%*	*11.6%*
	2019	*320*	*2.2%*	*47.6%*	*13.9%*	*26.4%*	*12.1%*
	2020	*340*	*2.2%*	*49.7%*	*9.3%*	*23.6%*	*17.4%*
	2022	*340*	*2.3%*	*45.7%*	*27.6%*	*14.6%*	*12.1%*
WC03	2010	300	1.7%	34.4%	0%	65.6%	0%
	2012	300	1.8%	24.0%	8.5%	54.9%	12.6%
	2013	306.3	1.6%	37.2%	15.9%	30.4%	16.5%
	2015	306	1.7%	32.0%	9.5%	34.0%	24.5%
	2017	*306*	*1.7%*	*52.4%*	*13.6%*	*23.5%*	*10.5%*
	2018	*309*	*1.7%*	*48.4%*	*14.3%*	*29.4%*	*7.8%*
	2019	*308*	*1.8%*	*46.0%*	*16.3%*	*28.1%*	*9.6%*
	2020	*308*	*1.8%*	*42.6%*	*7.4%*	*35.4%*	*14.6%*
	2022	*308*	*1.8%*	*49.0%*	*17.1%*	*28.2%*	*5.8%*
WC04	2010	300	3.5%	60.0%	0%	40.0%	0%
	2012	300	3.4%	41.3%	16.2%	30.3%	12.2%
	2013	300	3.4%	46.5%	11.0%	27.9%	14.6%
	2015	300	3.4%	50.3%	21.7%	19.0%	9.0%
	2017	*300*	*3.5%*	*48.2%*	*24.3%*	*14.0%*	*13.5%*
	2018	*300*	*3.7%*	*67.5%*	*13.0%*	*13.9%*	*5.2%*
	2019	*300*	*3.3%*	*70.0%*	*8.7%*	*13.3%*	*8.0%*
	2020	*300*	*3.5%*	*57.2%*	*18.3%*	*16.2%*	*8.3%*
	2022	*300*	*3.6%*	*67.4%*	*13.5%*	*12.2%*	*7.0%*

*Profiles and cross-sections re-established during Post-Restoration Year 1 (2017)

Table C-2. Comparisons of Cross-sectional Survey Analyses Pre-Restoration Years 1 – 4 (2010 – 2015) and Post-Restoration Years 1 – 5 (2017 – 2022)

Reach	Year	Station	Feature	Bankfull Width (ft)	Mean Depth (ft)	Width/ Depth Ratio	Entrench-ment Ratio	Bankfull Area (ft^2)	Top of Bank Area (ft^2)
WC01*	2010	2+30	Crossover Riffle	21.1	1.0	22.2	1.5	20.1	73.0
	2012	2+30	Crossover Riffle	21.3	1.1	18.6	1.5	24.5	78.1
	2013	2+29	Crossover Riffle	21.6	1.1	20.2	1.5	23.2	66.9
	2015	2+29	Crossover Riffle	21.0	1.0	21.6	1.5	20.5	74.8
	2017	*2+24*	*Crossover Riffle*	*20.7*	*0.8*	*26.8*	*1.7*	*16.0*	*164.4*
	2018	*2+24*	*Crossover Riffle*	*21.7*	*1.0*	*21.9*	*1.8*	*21.6*	*169.6*
	2019	*2+24*	*Crossover Riffle*	*28.8*	*0.7*	*41.2*	*1.4*	*20.1*	*161.7*
	2020	*2+24*	*Crossover Riffle*	*24.5*	*0.9*	*27.0*	*1.7*	*22.1*	*148.4*
	2022	*2+24*	*Crossover Riffle*	*24.1*	*0.9*	*27.1*	*1.6*	*21.4*	*131.1*
	2010	2+95	Meander/Riffle	22.1	0.8	26.0	1.5	18.8	230.1
	2012	2+95	Meander/Riffle	28.9	0.8	37.5	1.5	22.3	246.9
	2013	2+95	Meander/Riffle	29.0	0.9	34.1	1.5	24.7	212.7
	2015	2+95	Meander/Riffle	29.1	1.2	25.0	1.6	33.8	259.6
	2017	*2+71*	*Meander/Pool*	*21.3*	*2.0*	*10.7*	*1.4*	*42.6*	*269.7*
	2018	*2+71*	*Meander/Pool*	*21.5*	*1.5*	*14.5*	*1.8*	*31.8*	*236.4*
	2019	*2+71*	*Meander/Pool*	*20.3*	*1.5*	*13.5*	*2.0*	*30.6*	*223.0*
	2020	*2+71*	*Meander/Pool*	*13.9*	*1.8*	*7.6*	*2.1*	*25.4*	*144.7*
	2022	*2+71*	*Meander/Pool*	*13.1*	*1.4*	*9.3*	*2.1*	*18.5*	*111.3*
WC02*	2010	1+37	Crossover Riffle	13.1	0.7	18.4	1.2	9.3	31.6
	2012	1+38	Crossover Riffle	14.3	0.6	24.1	1.2	8.5	37.1
	2013	1+38	Crossover Riffle	14.3	0.7	19.4	1.2	10.6	36.7
	2015	1+38	Crossover Riffle	13.9	0.8	17.9	1.2	10.8	28.4
	2017	*1+10*	*Crossover Riffle*	*11.6*	*0.5*	*24.6*	*1.3*	*5.5*	*38.6*
	2018	*1+10*	*Crossover Riffle*	*13.6*	*0.7*	*20.8*	*1.4*	*8.9*	*56.5*
	2019	*1+10*	*Pool*	*12.6*	*0.7*	*17.4*	*1.3*	*9.1*	*38.4*
	2020	*1+10*	*Pool*	*11.9*	*0.6*	*18.6*	*1.2*	*7.6*	*35.3*
	2022	*1+10*	*Pool*	*12.2*	*0.6*	*22.0*	*1.1*	*6.8*	*35.4*
	2010	3+24	Meander/Riffle	16.7	0.9	19.3	1.3	14.5	70.3
	2012	3+24	Meander/Riffle	14.6	0.6	23.8	1.4	9.0	71.7
	2013	3+25.5	Meander/Riffle	15.6	0.7	21.8	1.5	11.1	72.0
	2015	3+24	Meander/Riffle	16.4	0.9	19.1	1.4	14.0	74.6
	2017	*0+74.5*	*Pool*	*13.6*	*1.3*	*10.2*	*1.3*	*18.2*	*49.0*
	2018	*0+74.5*	*Pool*	*11.6*	*0.7*	*16.5*	*1.4*	*8.1*	*43.5*
	2019	*0+74.5*	*Crossover Riffle*	*16.2*	*0.6*	*28.5*	*1.4*	*9.2*	*48.4*
	2020	*0+74.5*	*Crossover Riffle*	*14.8*	*0.4*	*38.1*	*1.3*	*5.7*	*21.8*
	2022	*0+74.5*	*Crossover Riffle*	*14.3*	*0.3*	*47.8*	*1.3*	*4.3*	*22.9*
WC03	2010	1+55	Crossover Riffle	9.2	0.4	24.1	1.1	3.5	37.5
	2012	1+57	Pool	10.6	1.1	9.8	1.3	11.4	41.3
	2013	1+56	Crossover Riffle	10.1	0.9	11.8	1.2	8.6	38.2
	2015	1+55	Crossover Riffle	9.3	0.7	12.7	1.2	6.8	37.9
	2017	*1+56*	*Crossover Riffle*	*7.3*	*0.9*	*8.6*	*1.7*	*7.3*	*35.0*
	2018	*1+56*	*Crossover Riffle*	*10.0*	*1.1*	*9.4*	*1.3*	*10.7*	*41.6*
	2019	*1+56*	*Crossover Riffle*	*10.4*	*0.9*	*11.7*	*1.3*	*9.2*	*42.3*
	2020	*1+56*	*Crossover Riffle*	*10.7*	*0.7*	*15.2*	*1.6*	*7.6*	*40.5*
	2022	*1+56*	*Crossover Riffle*	*10.4*	*0.7*	*13.9*	*1.3*	*7.8*	*42.4*
	2010	2+07	Meander/Pool	7.2	0.5	13.0	1.9	3.9	43.8

Table C-2. (Continued)									
Reach	**Year**	**Station**	**Feature**	**Bankfull Width (ft)**	**Mean Depth (ft)**	**Width/ Depth Ratio**	**Entrench-ment Ratio**	**Bankfull Area (ft^2)**	**Top of Bank Area (ft^2)**
WC03	2012	2+08	Meander/Pool	10.2	1.2	8.4	2.5	12.5	56.2
	2013	2+12	Meander/Pool	9.7	1.0	10.0	2.7	9.4	55.0
	2015	2+07	Meander/Pool	9.9	1.1	9.4	2.8	10.5	61.4
	2017	*2+08*	*Meander/Run*	*9.8*	*0.9*	*12.2*	*2.7*	*9.8*	*61.5*
	2018	*2+08*	*Meander/Run*	*11.5*	*0.6*	*18.3*	*2.3*	*7.2*	*61.8*
	2019	*2+08*	*Meander/Run*	*11.6*	*0.7*	*15.9*	*1.6*	*8.5*	*62.6*
	2020	*2+08*	*Meander/Run*	*13.0*	*1.3*	*10.4*	*2.7*	*16.2*	*32.1*
	2022	*2+08*	*Meander/Run*	*14.7*	*1.2*	*12.1*	*2.4*	*17.9*	*34.8*
WC04	2010	1+08	Meander/Riffle	4.3	0.4	9.8	4.3	1.9	92.5
	2012	1+08	Meander/Pool	6.7	0.6	11.4	3.9	4.0	95.9
	2013	1+08	Meander/Pool	13.0	0.6	23.5	2.2	7.2	99.9
	2015	1+08	Meander/Pool	13.6	0.6	24.0	2.3	7.7	102.8
	2017	*1+10*	*Meander/Pool*	*20.6*	*0.4*	*51.3*	*1.5*	*8.3*	*99.8*
	2018	*1+10*	*Meander/Pool*	*6.8*	*0.6*	*13.6*	*3.4*	*4.5*	*93.4*
	2019	*1+10*	*Meander/Pool*	*11.6*	*0.4*	*28.8*	*2.7*	*4.7*	*90.7*
	2020	*1+10*	*Meander/Pool*	*7.8*	*0.7*	*10.5*	*4.2*	*5.8*	*90.9*
	2022	*1+10*	*Meander/Pool*	*7.6*	*0.8*	*9.9*	*4.2*	*5.8*	*80.3*
	2010	1+68	Crossover Riffle	8.9	0.4	24.0	1.4	3.3	55.9
	2012	1+68	Crossover Riffle	9.2	0.5	18.9	1.5	4.4	57.8
	2013	1+68	Crossover Riffle	10.4	0.5	20.4	1.4	5.3	56.3
	2015	1+68	Crossover Riffle	11.1	0.6	17.4	1.6	7.1	55.6
	2017	*1+68*	*Crossover Riffle*	*10.4*	*0.5*	*22.3*	*1.4*	*4.8*	*54.8*
	2018	*1+68*	*Crossover Riffle*	*9.2*	*0.3*	*28.8*	*1.3*	*3.0*	*55.4*
	2019	*1+68*	*Crossover Riffle*	*9.7*	*0.4*	*24.1*	*1.4*	*3.9*	*56.0*
	2020	*1+68*	*Crossover Riffle*	*9.4*	*0.3*	*27.4*	*1.4*	*3.3*	*55.7*
	2022	*1+68*	*Crossover Riffle*	*11.0*	*0.4*	*27.1*	*1.4*	*4.4*	*55.5*

*Profiles and cross-sections re-established during Post-Restoration Year 1 (2017)

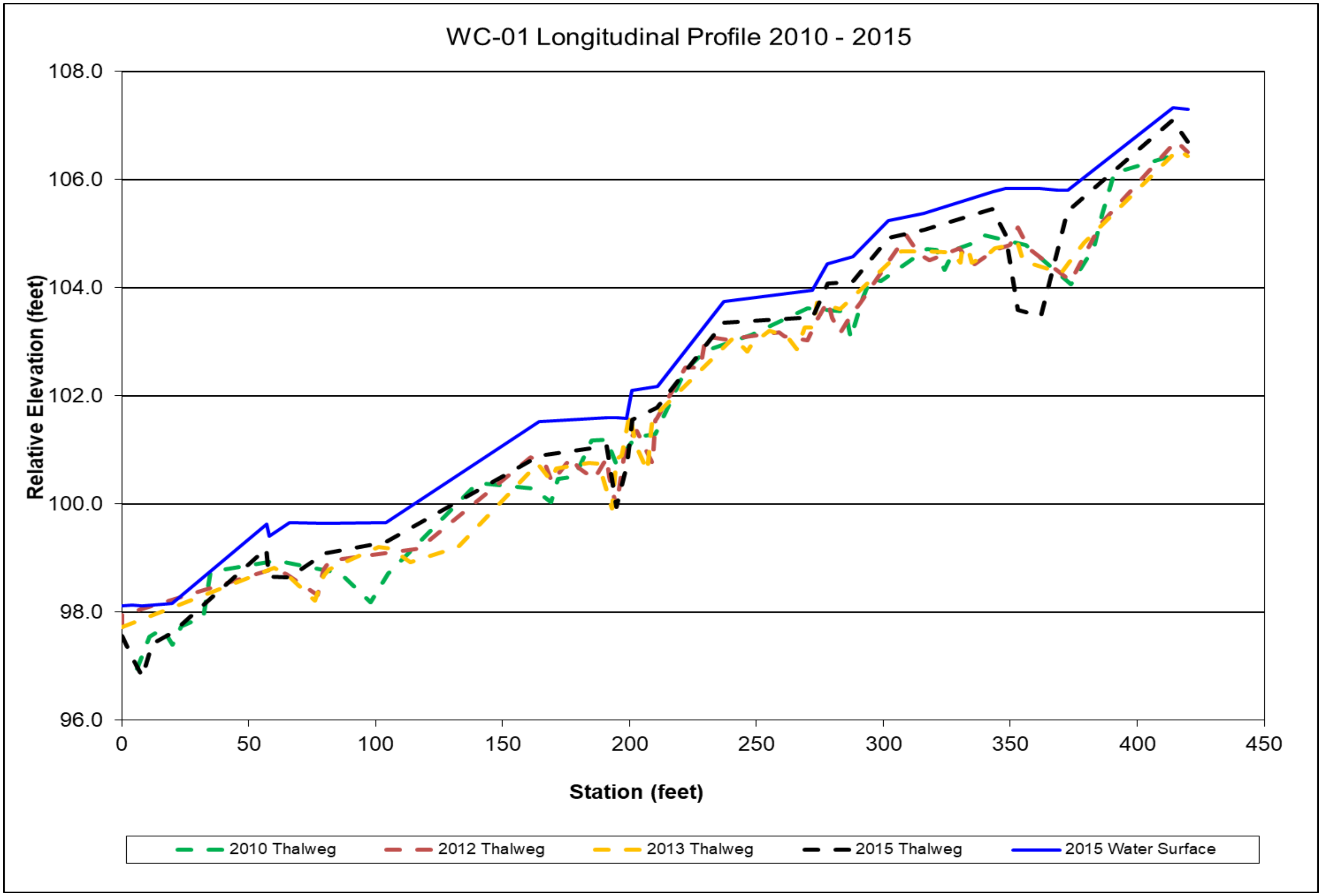

Figure C-1. WC-01 Longitudinal Profile (Pre-Restoration)

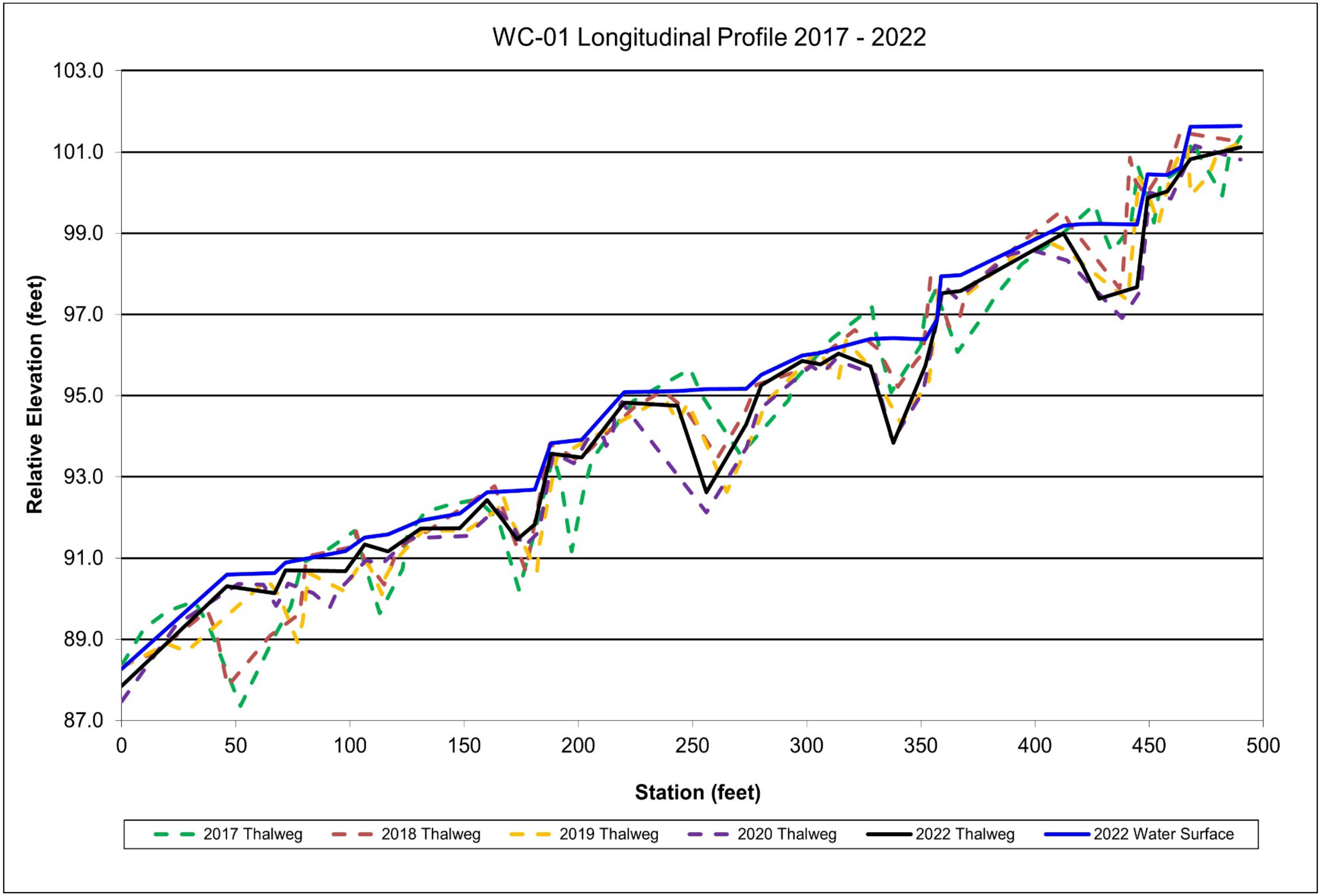

Figure C-2. WC-01 Longitudinal Profile (Post-Restoration)

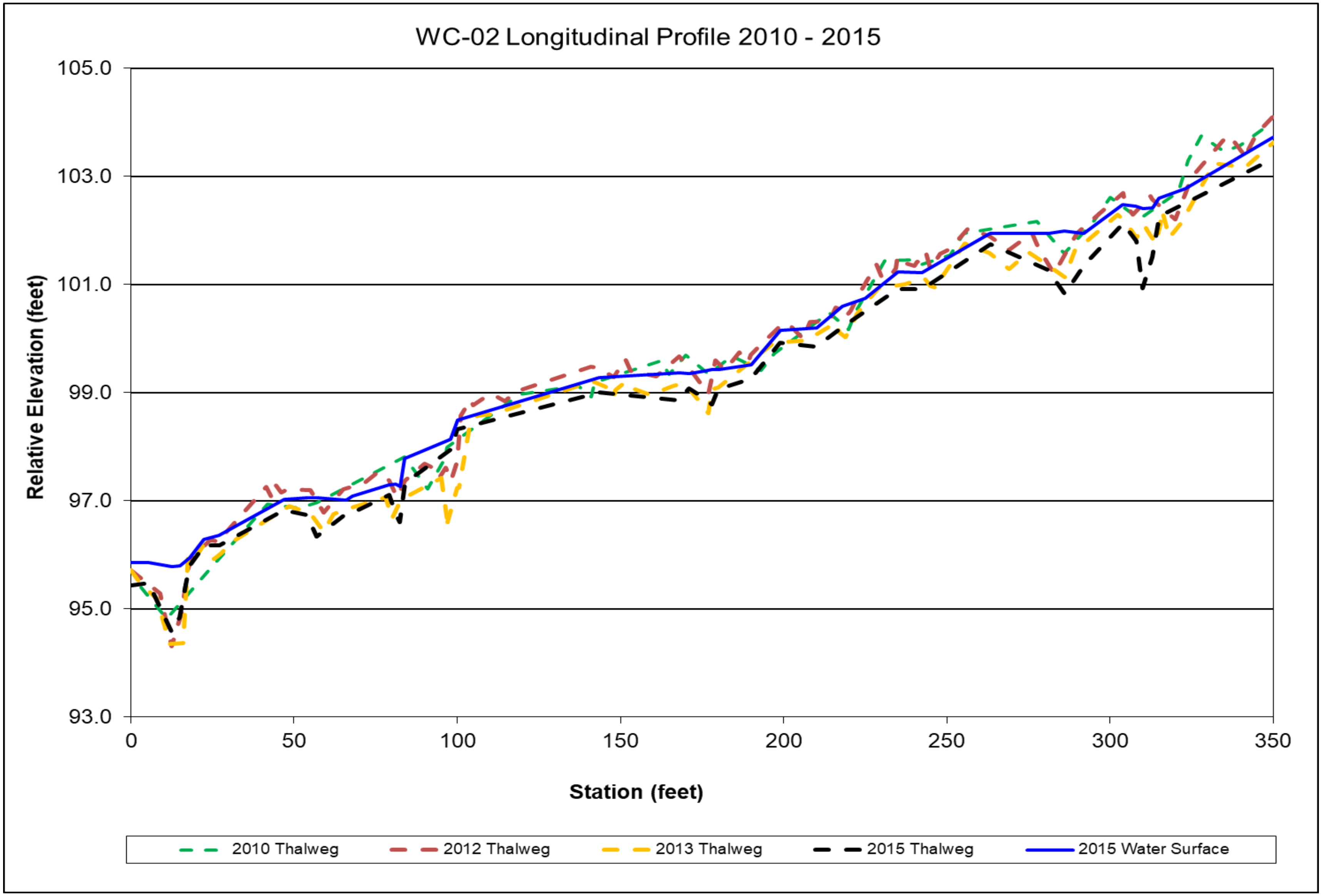

Figure C-3. WC-02 Longitudinal Profile (Pre-Restoration)

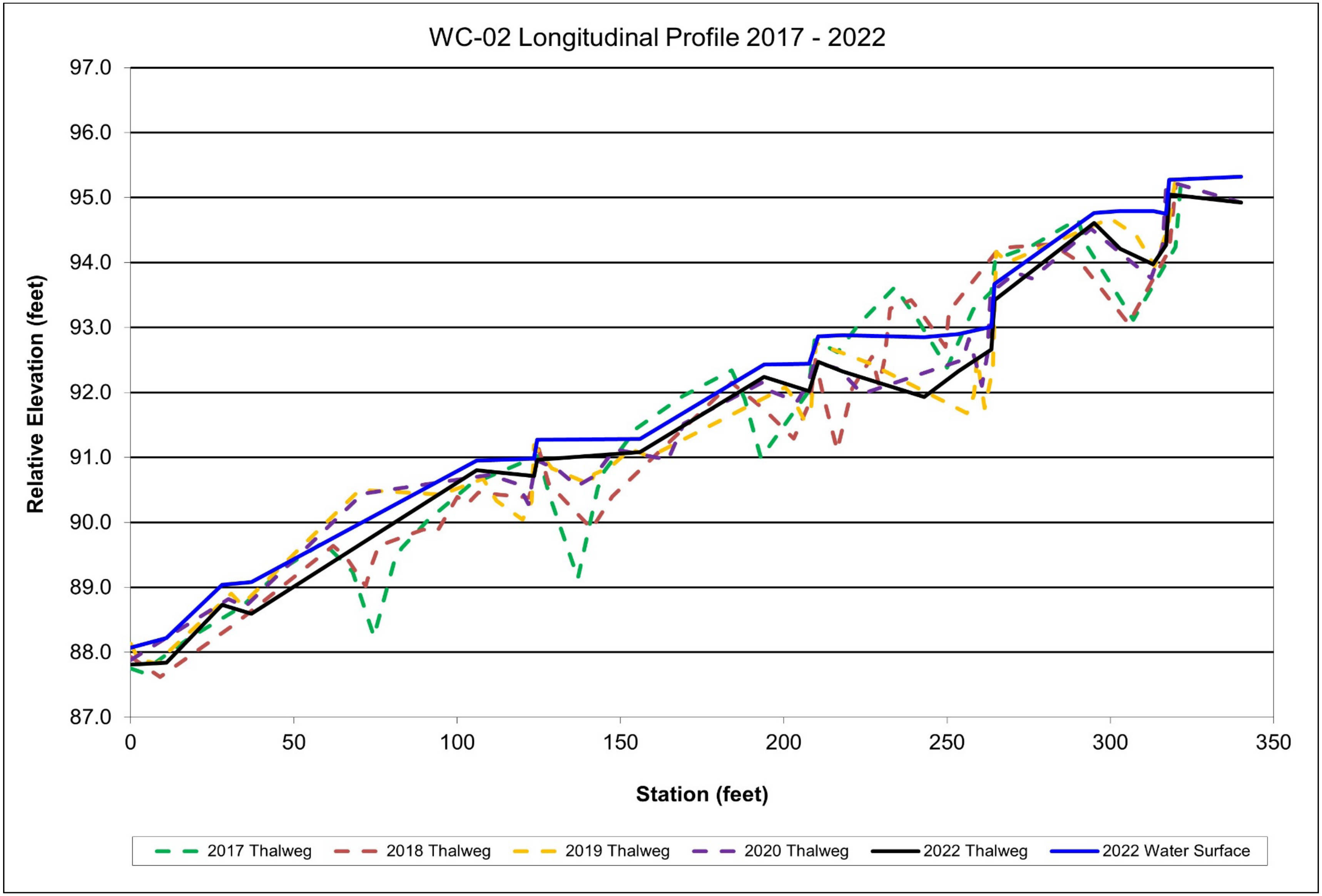

Figure C-4. WC-02 Longitudinal Profile (Post-Restoration)

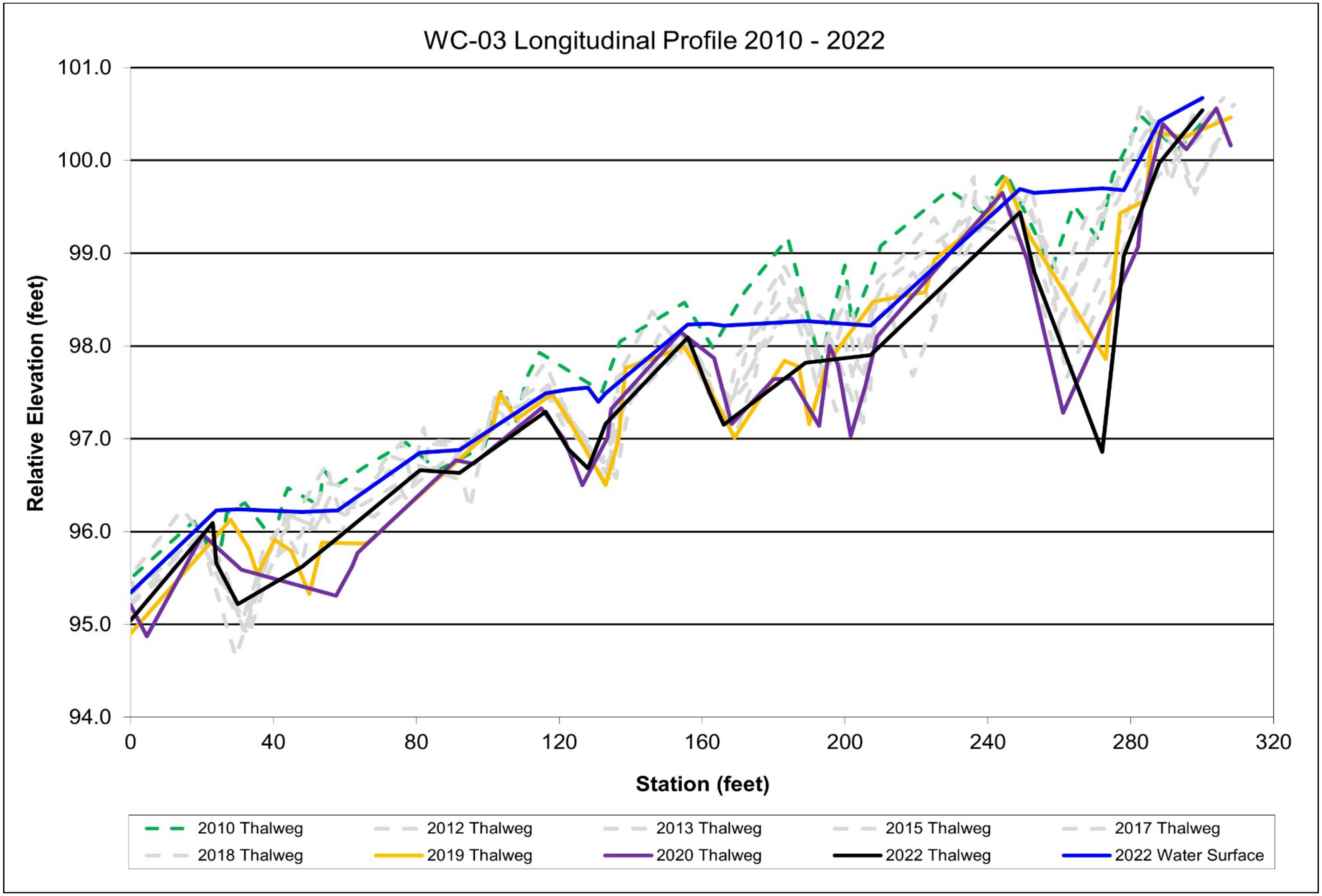

Figure C-5. WC-03 Longitudinal Profile (Pre- and Post-Restoration)

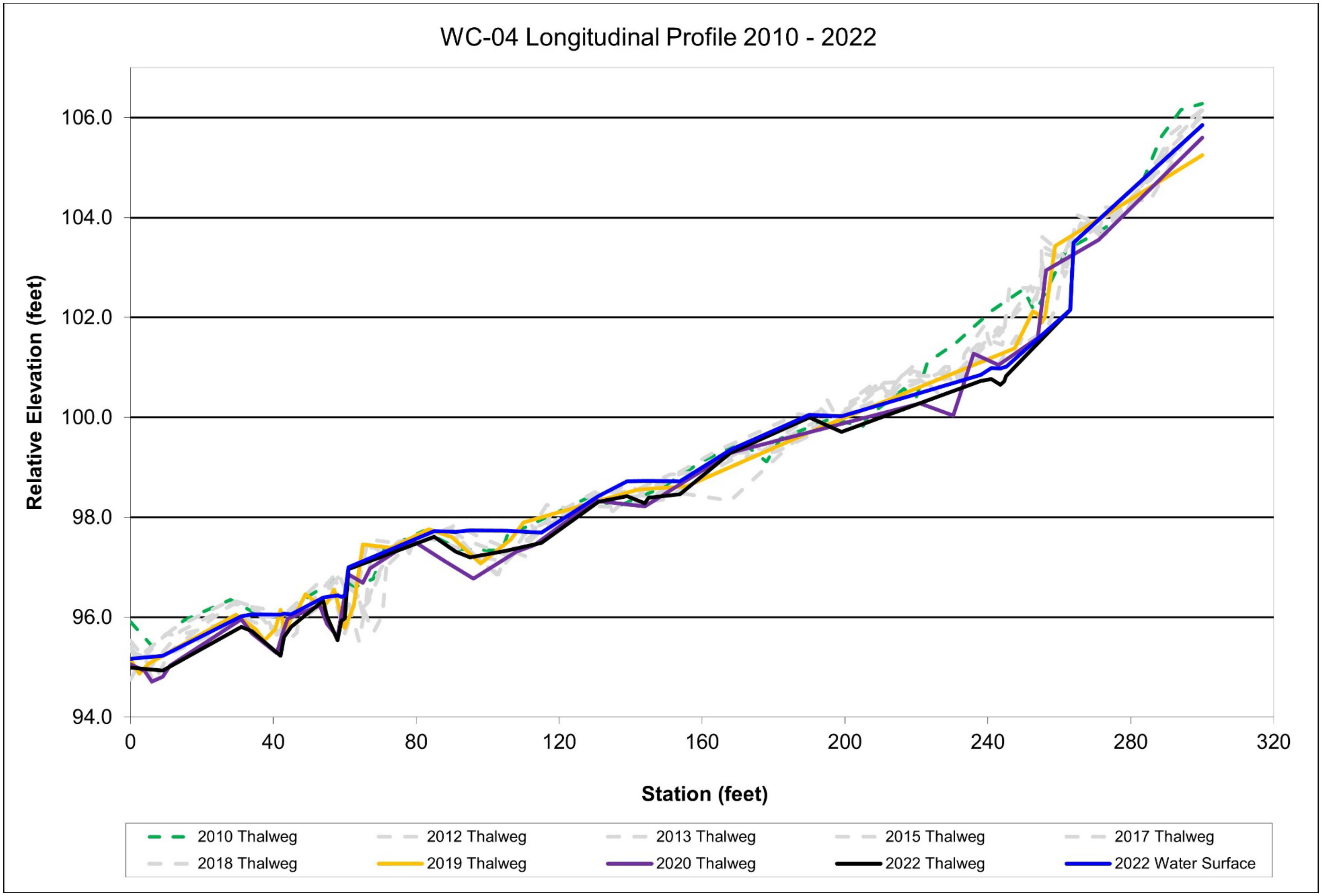

Figure C-6. WC-04 Longitudinal Profile (Pre- and Post-Restoration)

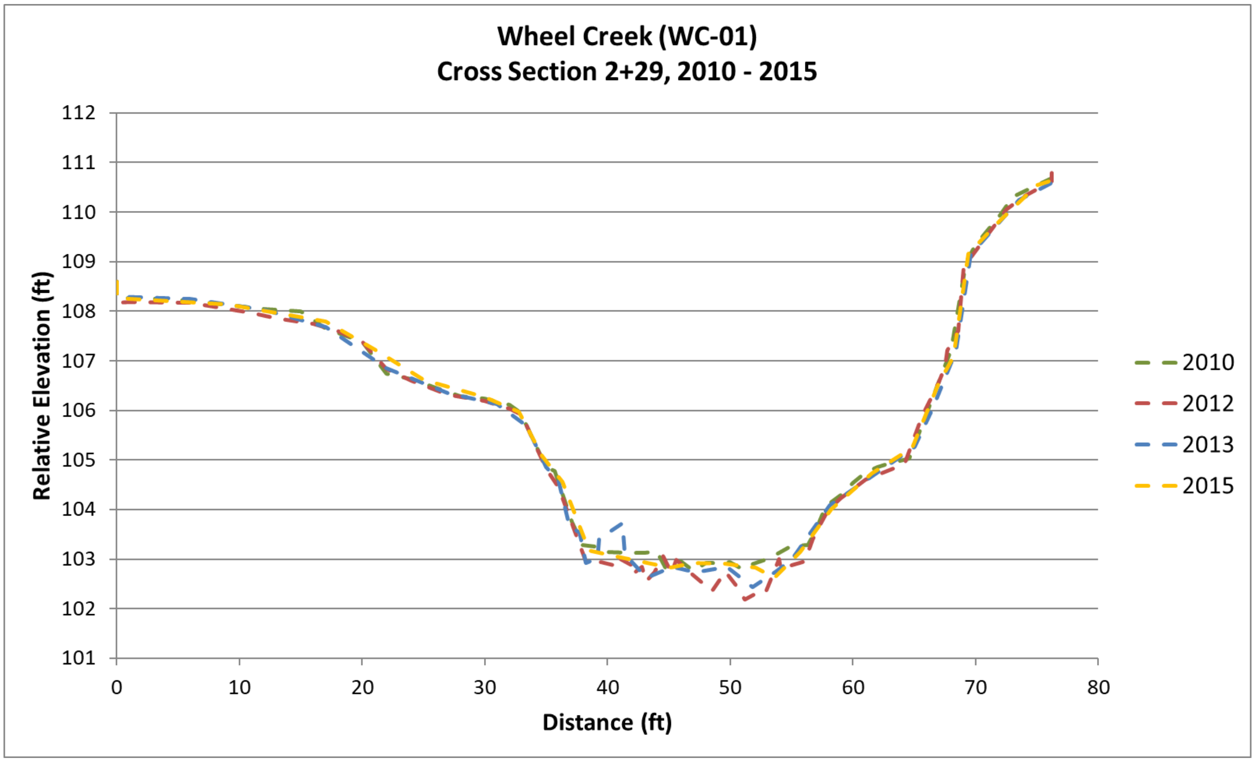

Figure C-7. WC01 Cross-section 1 (Pre-Restoration)

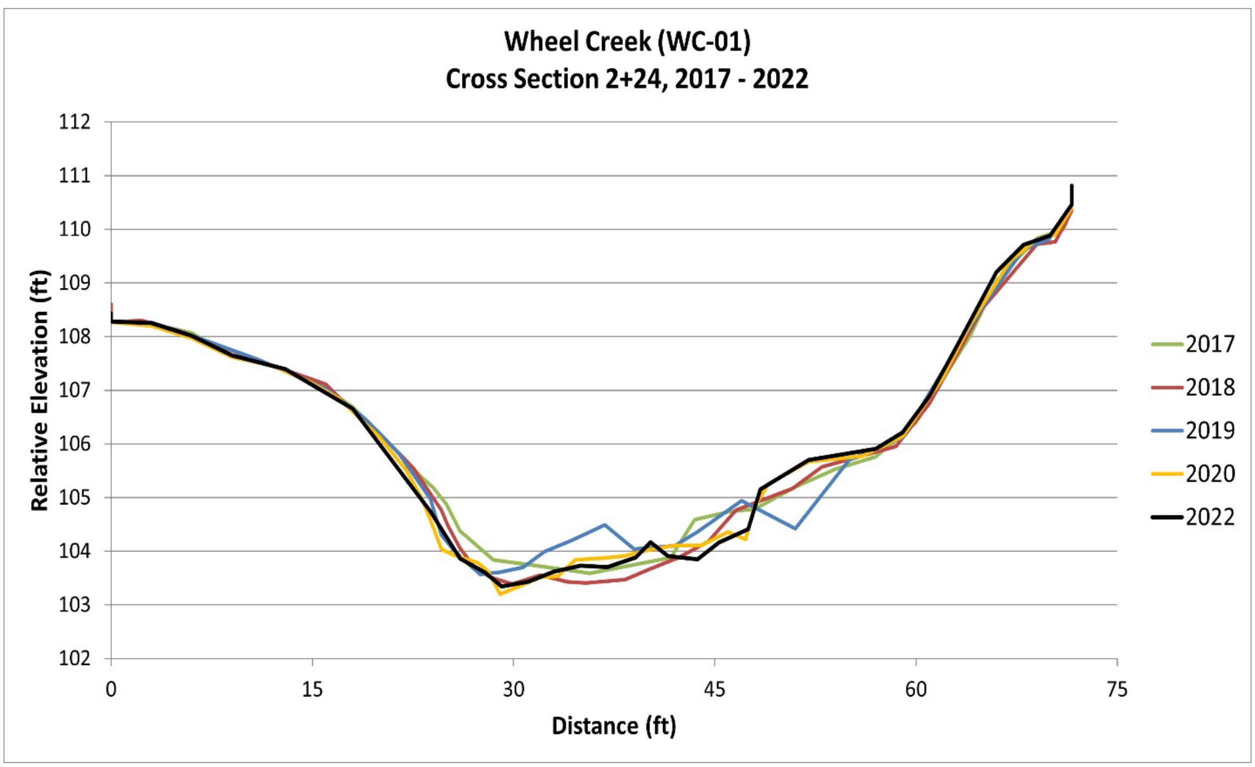

Figure C-8. WC01 Cross-section 1 (Post-Restoration)

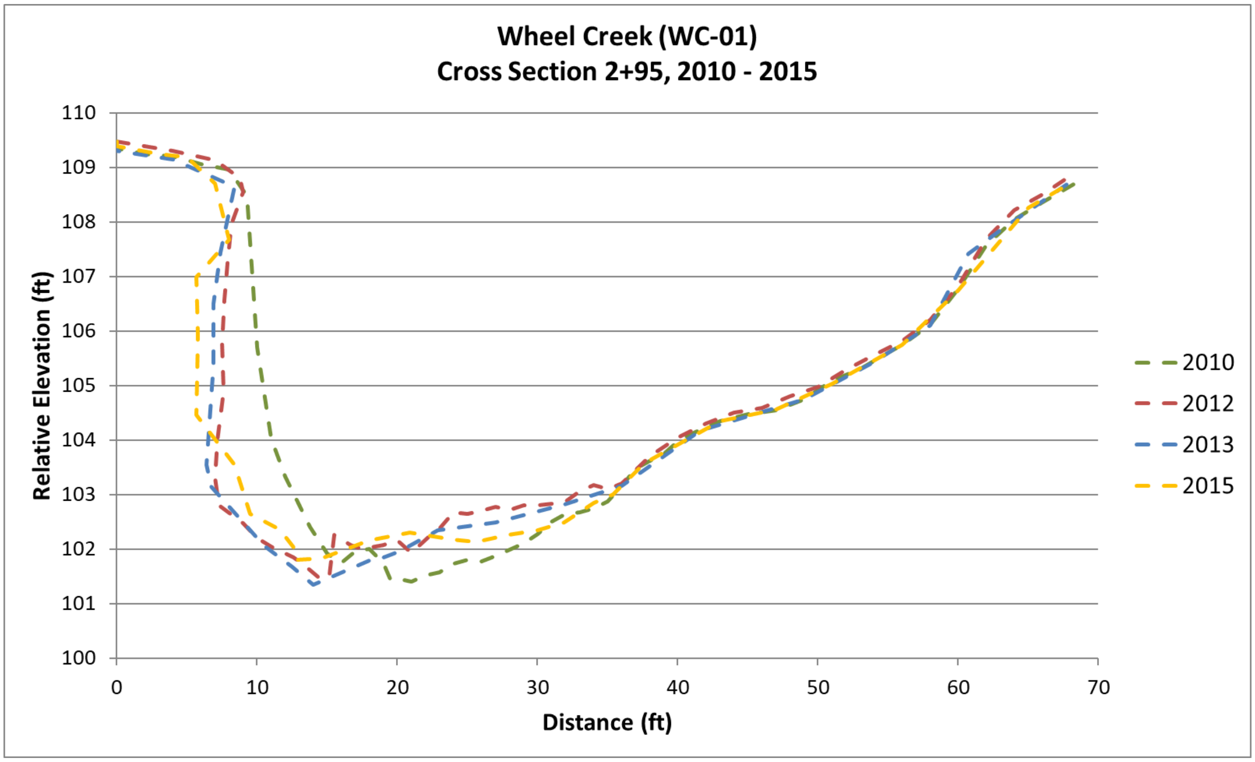

Figure C-9. WC01 Cross-section 2 (Pre-Restoration)

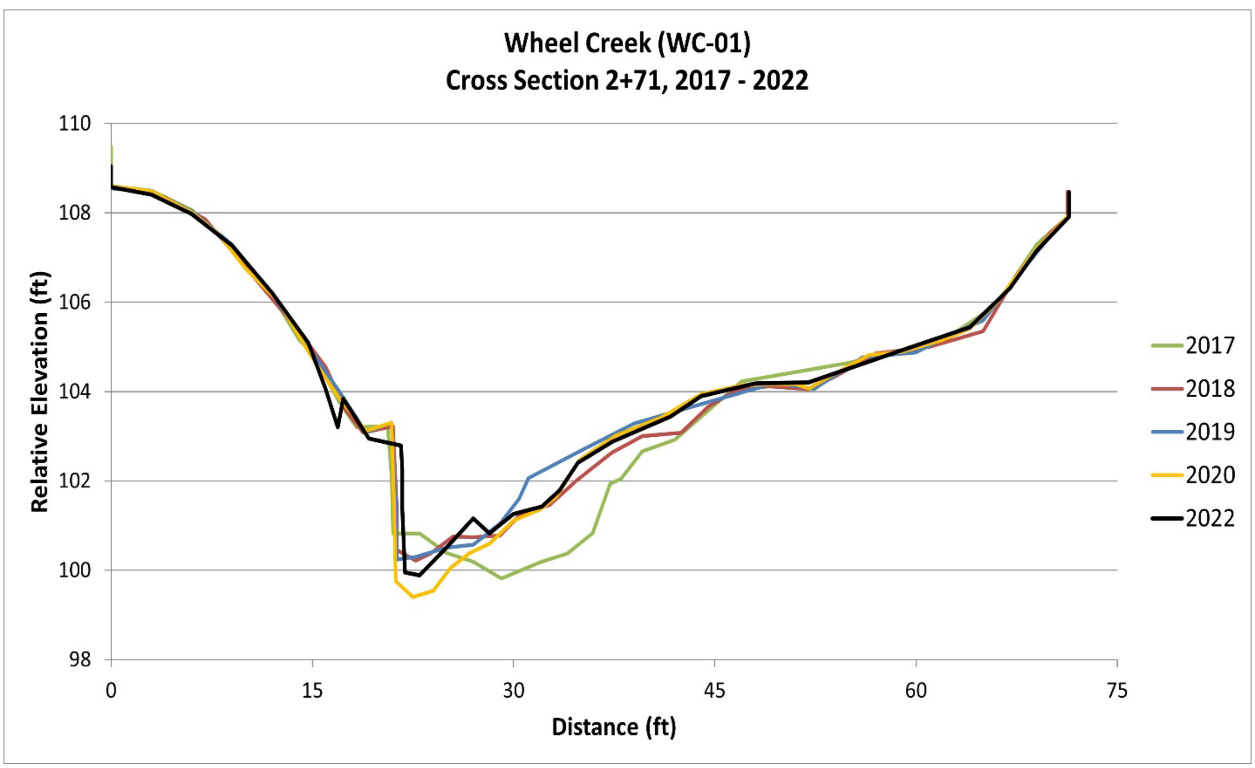

Figure C-10. WC01 Cross-section 2 (Post-Restoration)

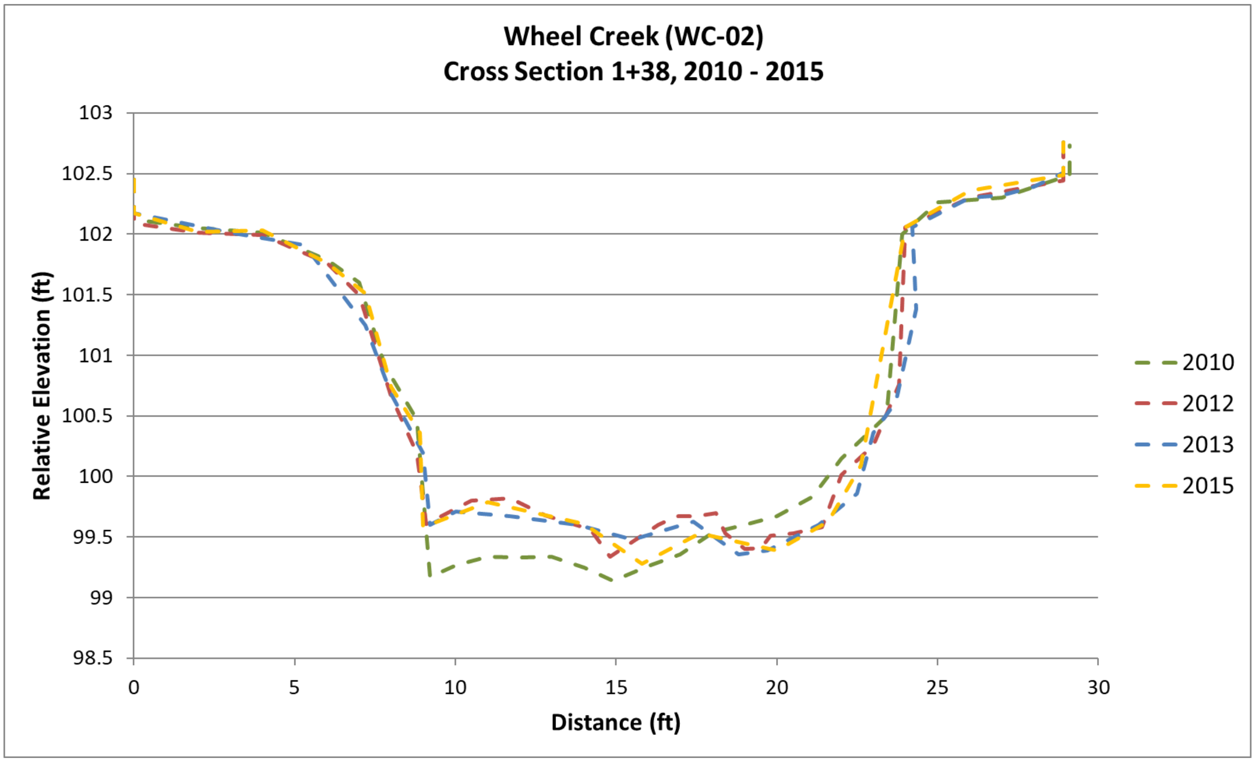

Figure C-11. WC02 Cross-section 1 (Pre-Restoration)

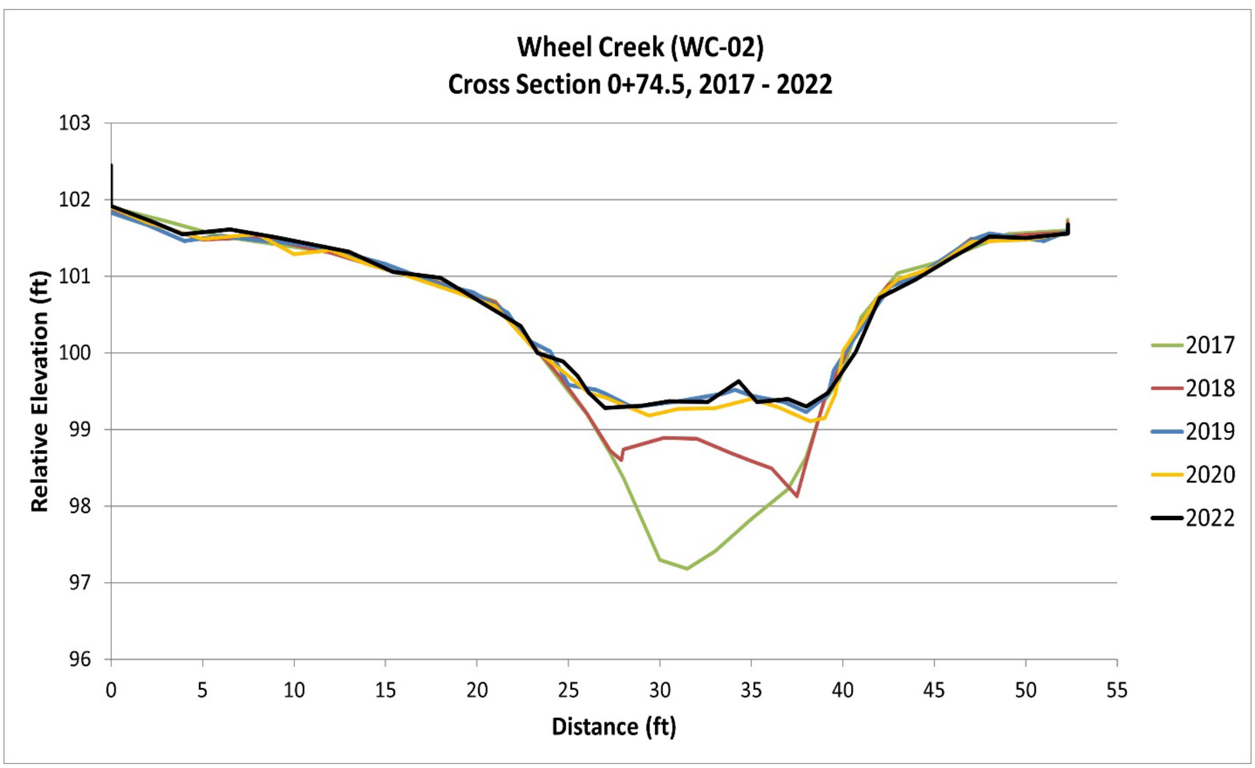

Figure C-12. WC02 Cross-section 1 (Post-Restoration)

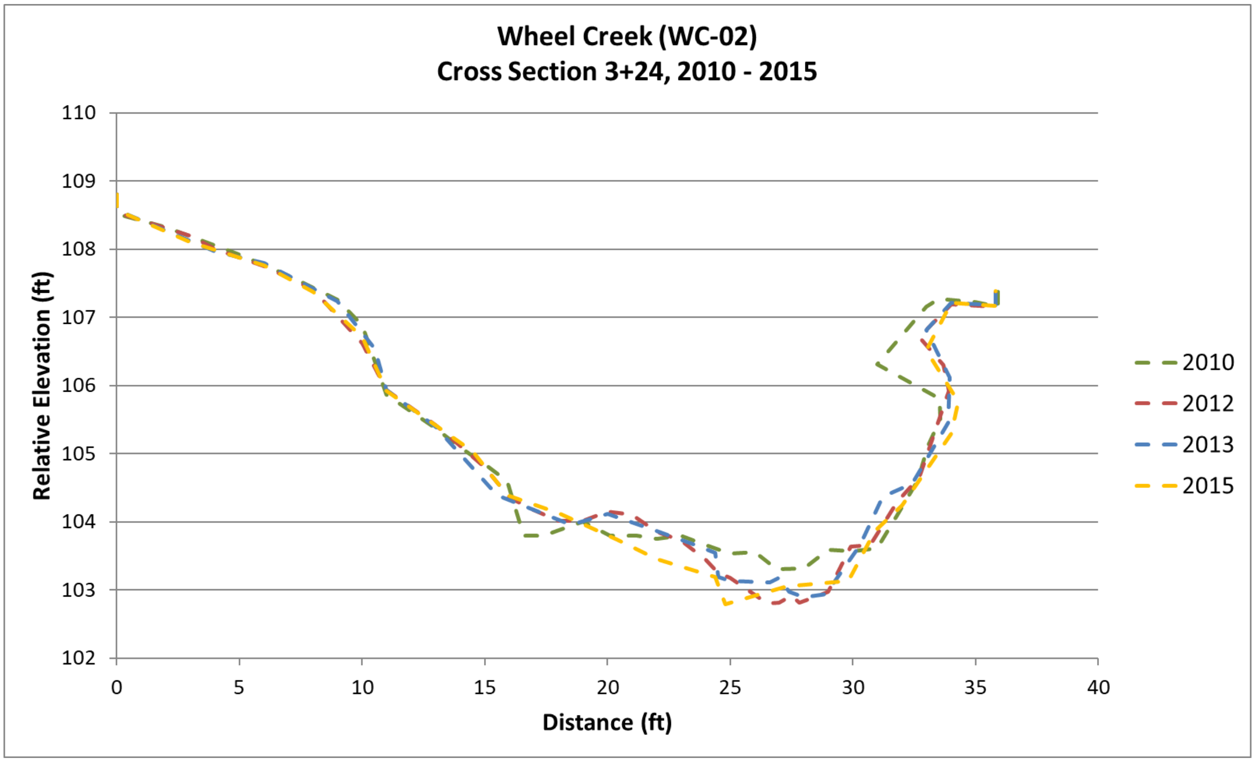

Figure C-13. WC02 Cross-section 2 (Pre-Restoration)

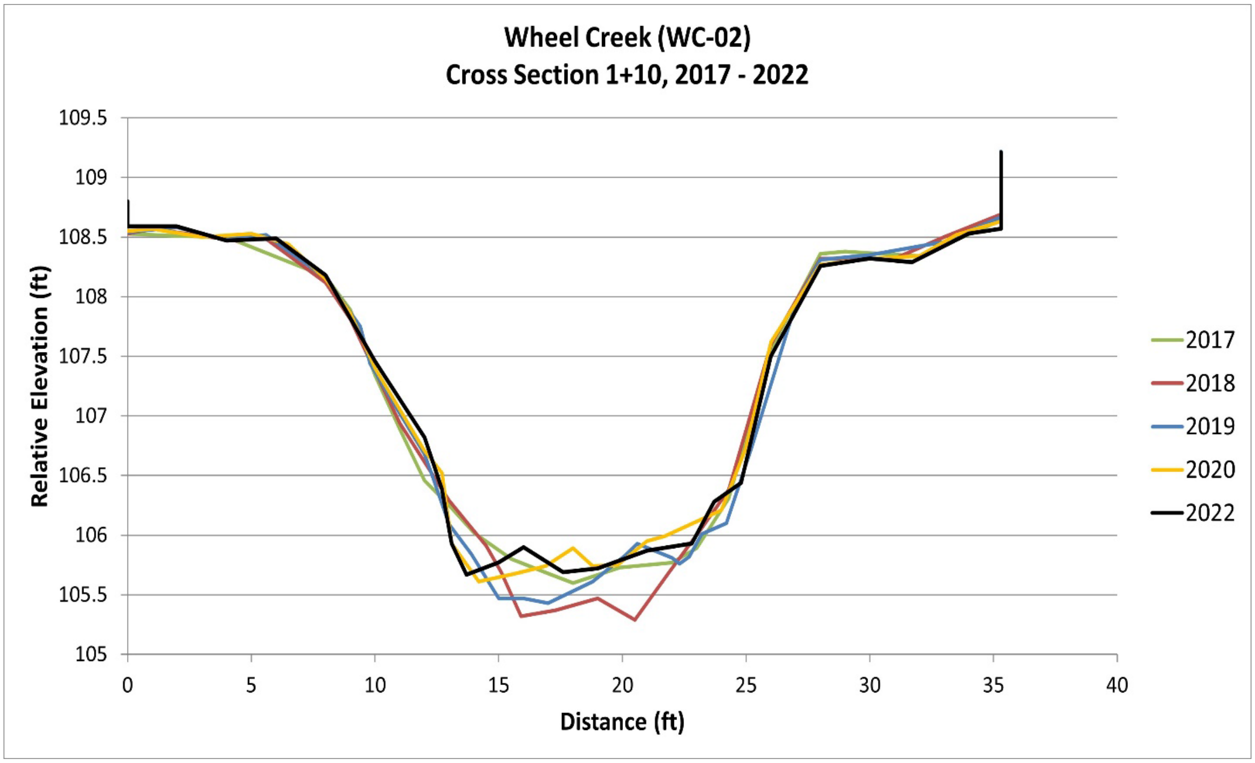

Figure C-14. WC02 Cross-section 2 (Post-Restoration)

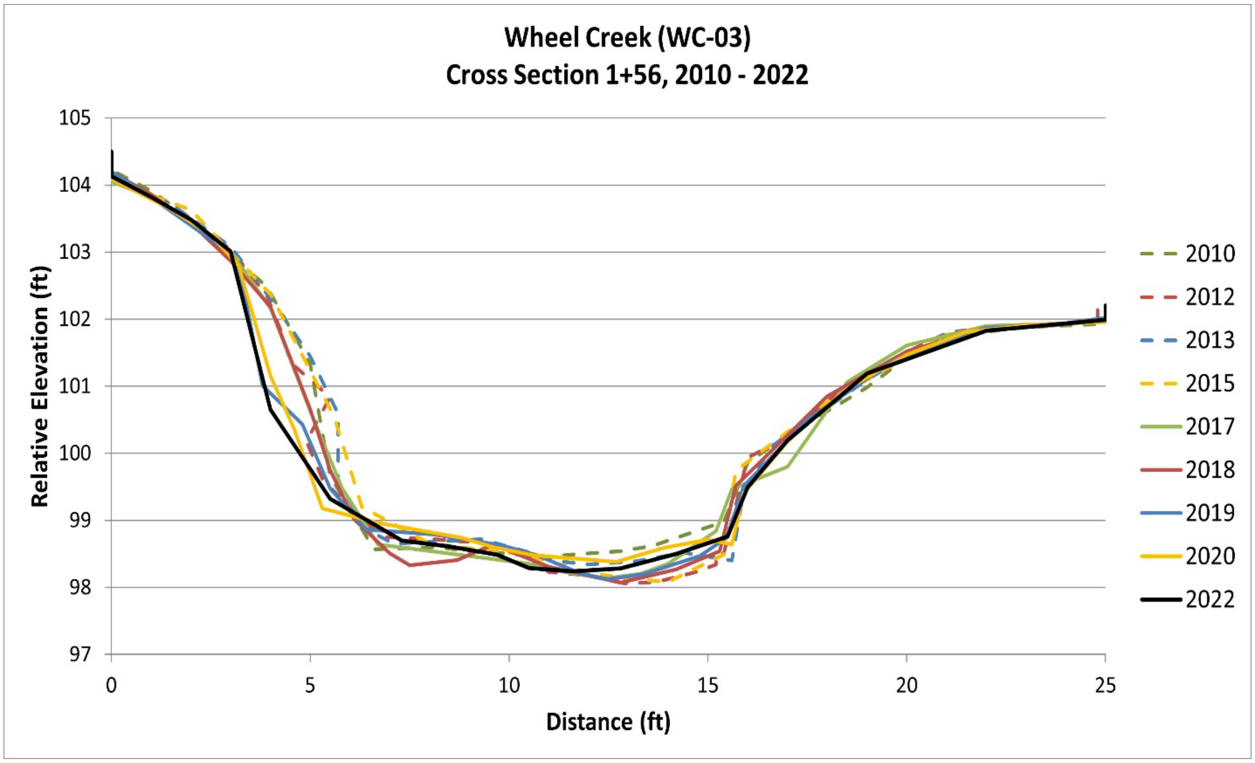

Figure C-15. WC03 Cross-section 1 (Pre- and Post-Restoration)

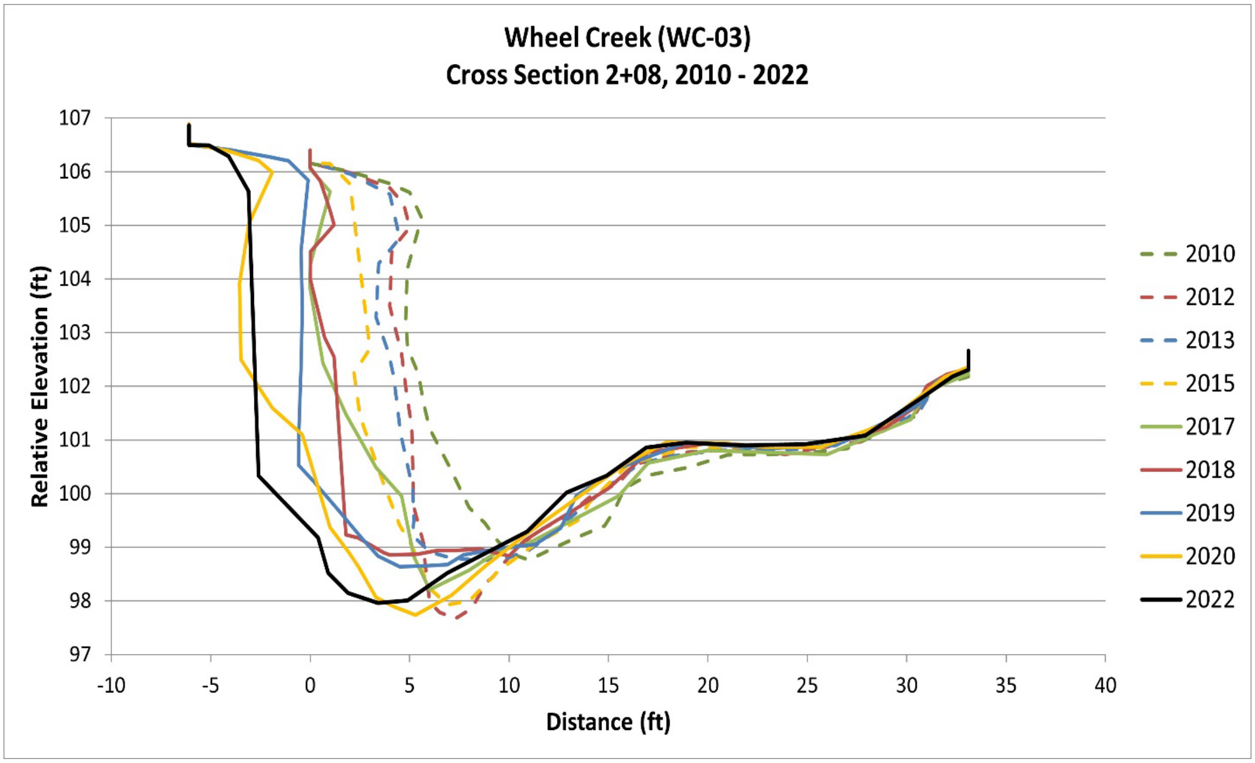

Figure C-16. WC03 Cross-section 2 (Pre- and Post-Restoration)

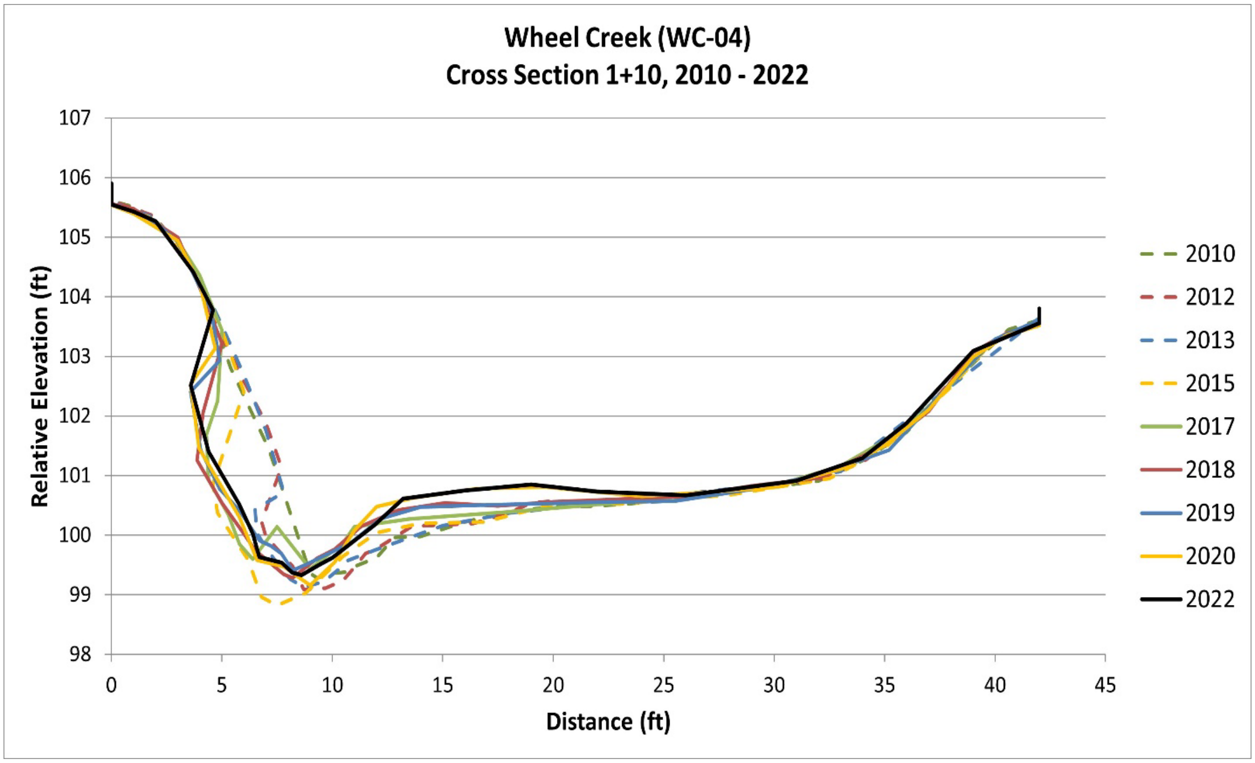

Figure C-17. WC04 Cross-section 1 (Pre- and Post-Restoration)

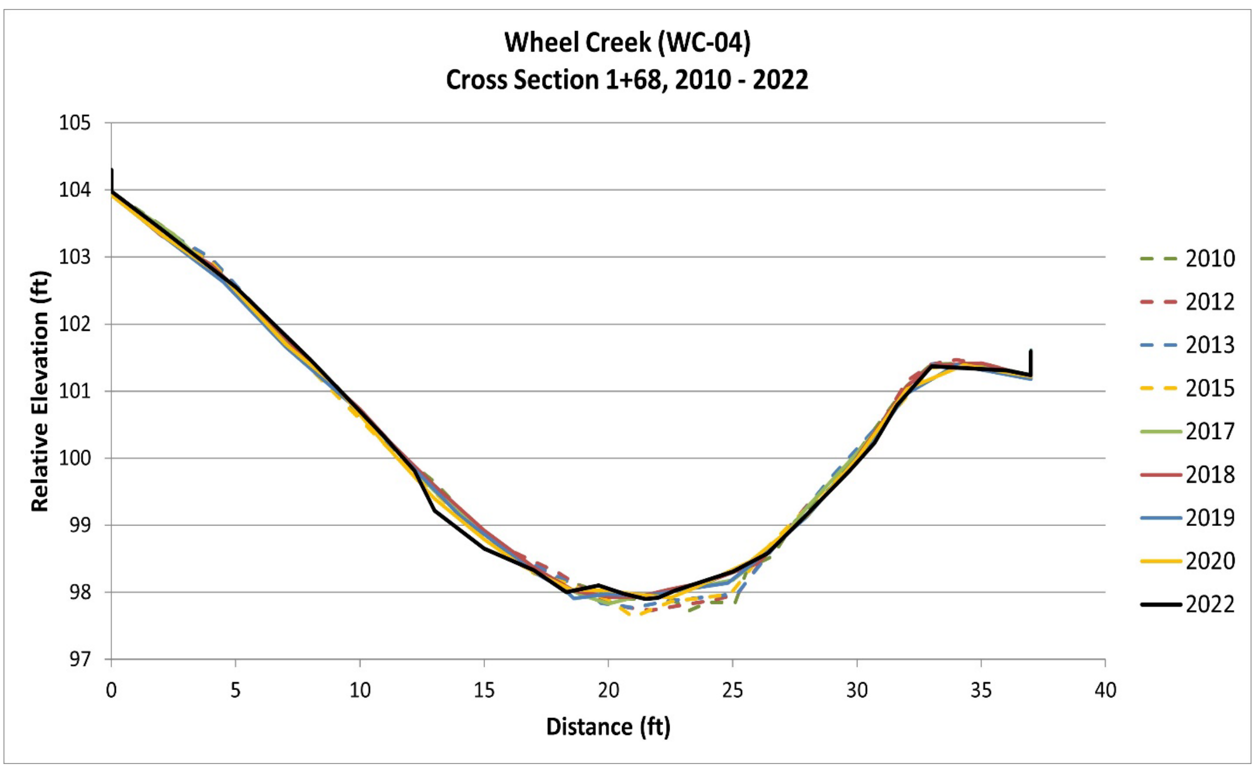

Figure C-18. WC04 Cross-section 2 (Pre- and Post-Restoration)

Table C-3. Particle Size Distribution Pre-Restoration Years 1 – 4, Post-Restoration Years 1 – 5

Year	*Riffle Feature Surface*			*Meander Feature Surface*			*Reachwide*		
	Measure	Size (mm)	Size Class	Measure	Size (mm)	Size Class	Measure	Size (mm)	Size Class
WC01*									
2010	D50	39	very coarse gravel	D50	38	very coarse gravel	D50	44	very coarse gravel
2012	D50	56	very coarse gravel	D50	40	very coarse gravel	D50	51	very coarse gravel
2013	D50	49	very coarse gravel	D50	37	very coarse gravel	D50	55	very coarse gravel
2015	D50	50	very coarse gravel	D50	55	very coarse gravel	D50	42	very coarse gravel
2017	*D50*	*52*	*very coarse gravel*	*D50*	*11*	*medium gravel*	*D50*	*25*	*coarse gravel*
2018	*D50*	*41*	*very coarse gravel*	*D50*	*32*	*very coarse gravel*	*D50*	*47*	*very coarse gravel*
2019	*D50*	*47*	*very coarse gravel*	*D50*	*12*	*medium gravel*	*D50*	*37*	*very coarse gravel*
2020	*D50*	*42*	*very coarse gravel*	*D50*	*25*	*coarse gravel*	*D50*	*32*	*coarse gravel*
2022	*D50*	*83*	*small cobble*	*D50*	*68*	*small cobble*	*D50*	*82*	*small cobble*
2010	D84	120	medium cobble	D84	90	medium cobble	D84	140	large cobble
2012	D84	180	large cobble	D84	77	small cobble	D84	120	medium cobble
2013	D84	130	large cobble	D84	87	small cobble	D84	130	large cobble
2015	D84	160	large cobble	D84	110	medium cobble	D84	150	large cobble
2017	*D84*	*120*	*small cobble*	*D84*	*57*	*very coarse gravel*	*D84*	*90*	*small cobble*
2018	*D84*	*150*	*large cobble*	*D84*	*97*	*medium cobble*	*D84*	*160*	*large cobble*
2019	*D84*	*110*	*medium cobble*	*D84*	*51*	*very coarse gravel*	*D84*	*90*	*small cobble*
2020	*D84*	*110*	*medium cobble*	*D84*	*84*	*small cobble*	*D84*	*93*	*medium cobble*
2022	*D84*	*170*	*large cobble*	*D84*	*120*	*medium cobble*	*D84*	*160*	*large cobble*
WC02*									
2010	D50	50	very coarse gravel	D50	45	very coarse gravel	D50	49	very coarse gravel
2012	D50	40	very coarse gravel	D50	33	very coarse gravel	D50	28	coarse gravel
2013	D50	51	very coarse gravel	D50	47	very coarse gravel	D50	40	coarse gravel
2015	D50	36	very coarse gravel	D50	26	very coarse gravel	D50	36	very coarse gravel
2017	*D50*	*26*	*coarse gravel*	*D50*	*4.3*	*very fine gravel*	*D50*	*16*	*medium gravel*
2018	*D50*	*41*	*very coarse gravel*	*D50*	*64*	*small cobble*	*D50*	*27*	*coarse gravel*
2019	*D50*	*51*	*very coarse gravel*	*D50*	*16*	*medium gravel*	*D50*	*22*	*coarse gravel*
2020	*D50*	*82*	*small cobble*	*D50*	*43*	*very coarse gravel*	*D50*	*37*	*very coarse gravel*
2022	*D50*	*28*	*coarse gravel*	*D50*	*34*	*very coarse gravel*	*D50*	*43*	*very coarse gravel*
2010	D84	98	medium cobble	D84	94	medium cobble	D84	100	medium cobble
2012	D84	80	small cobble	D84	69	small cobble	D84	80	small cobble
2013	D84	88	small cobble	D84	86	small cobble	D84	110	medium cobble
2015	D84	100	medium cobble	D84	100	medium cobble	D84	110	medium cobble
2017	*D84*	*85*	*very coarse gravel*	*D84*	*19*	*medium gravel*	*D84*	*62*	*very coarse gravel*
2018	*D84*	*120*	*medium cobble*	*D84*	*130*	*large cobble*	*D84*	*110*	*medium cobble*
2019	*D84*	*110*	*medium cobble*	*D84*	*64*	*small cobble*	*D84*	*76*	*small cobble*
2020	*D84*	*150*	*large cobble*	*D84*	*100*	*medium cobble*	*D84*	*80*	*small cobble*
2022	*D84*	*61*	*very coarse gravel*	*D84*	*68*	*small cobble*	*D84*	*88*	*small cobble*
WC03									
2010	D50	33	very coarse gravel	D50	8.7	medium gravel	D50	28	coarse gravel
2012	D50	27	coarse gravel	D50	15	medium gravel	D50	23	coarse gravel
2013	D50	27	coarse gravel	D50	29	coarse gravel	D50	35	very coarse gravel
2015	D50	36	very coarse gravel	D50	7.2	fine gravel	D50	26	coarse gravel
2017	*D50*	*26*	*coarse gravel*	*D50*	*17*	*medium gravel*	*D50*	*16*	*medium gravel*
2018	*D50*	*26*	*coarse gravel*	*D50*	*14*	*medium gravel*	*D50*	*22*	*coarse gravel*
2019	*D50*	*45*	*very coarse gravel*	*D50*	*23*	*coarse gravel*	*D50*	*22*	*coarse gravel*
2020	*D50*	*36*	*very coarse gravel*	*D50*	*12*	*medium gravel*	*D50*	*31*	*coarse gravel*
2022	*D50*	*28*	*coarse gravel*	*D50*	*20*	*coarse gravel*	*D50*	*21*	*coarse gravel*
2010	D84	74	small cobble	D84	72	small cobble	D84	75	small cobble
2012	D84	59	very coarse gravel	D84	43	very coarse gravel	D84	72	small cobble
2013	D84	68	small cobble	D84	59	very coarse gravel	D84	130	large cobble
2015	D84	85	small cobble	D84	30	coarse gravel	D84	69	small cobble
2017	*D84*	*59*	*very coarse gravel*	*D84*	*61*	*very coarse gravel*	*D84*	*50*	*very coarse gravel*
2018	*D84*	*69*	*small cobble*	*D84*	*50*	*very coarse gravel*	*D84*	*51*	*very coarse gravel*
2019	*D84*	*88*	*small cobble*	*D84*	*70*	*small cobble*	*D84*	*80*	*small cobble*

Table C-3. (Continued)

Year	Riffle Feature Surface			Meander Feature Surface			Reachwide		
	Measure	**Size (mm)**	**Size Class**	**Measure**	**Size (mm)**	**Size Class**	**Measure**	**Size (mm)**	**Size Class**
WC03									
2020	*D84*	*77*	*small cobble*	*D84*	*44*	*very coarse gravel*	*D84*	*71*	*small cobble*
2022	*D84*	*61*	*very coarse gravel*	*D84*	*47*	*very coarse gravel*	*D84*	*56*	*very coarse gravel*
WC04									
2010	D50	30	coarse gravel	D50	18	coarse gravel	D50	22	coarse gravel
2012	D50	36	very coarse gravel	D50	15	medium gravel	D50	24	coarse gravel
2013	D50	33	very coarse gravel	D50	1.5	very coarse sand	D50	36	very coarse gravel
2015	D50	35	very coarse gravel	D50	8.3	medium gravel	D50	28	coarse gravel
2017	*D50*	*43*	*coarse gravel*	*D50*	*12*	*medium gravel*	*D50*	*21*	*medium gravel*
2018	*D50*	*33*	*very coarse gravel*	*D50*	*1.9*	*very coarse sand*	*D50*	*17*	*coarse gravel*
2019	*D50*	*27*	*coarse gravel*	*D50*	*1.2*	*very coarse sand*	*D50*	*23*	*coarse gravel*
2020	*D50*	*49*	*very coarse gravel*	*D50*	*20*	*coarse sand*	*D50*	*22*	*coarse gravel*
2022	*D50*	*19*	*coarse gravel*	*D50*	*15*	*medium gravel*	*D50*	*11*	*medium gravel*
2010	D84	80	small cobble	D84	87	small cobble	D84	71	small cobble
2012	D84	64	small cobble	D84	70	small cobble	D84	76	small cobble
2013	D84	57	very coarse gravel	D84	64	small cobble	D84	79	small cobble
2015	D84	66	small cobble	D84	24	coarse gravel	D84	72	small cobble
2017	*D84*	*99*	*small cobble*	*D84*	*26*	*coarse gravel*	*D84*	*68*	*very coarse gravel*
2018	*D84*	*70*	*small cobble*	*D84*	*32*	*very coarse gravel*	*D84*	*47*	*very coarse gravel*
2019	*D84*	*80*	*small cobble*	*D84*	*29*	*coarse gravel*	*D84*	*81*	*small cobble*
2020	*D84*	*92*	*medium cobble*	*D84*	*58*	*very coarse gravel*	*D84*	*75*	*small cobble*
2022	*D84*	*41*	*very coarse gravel*	*D84*	*58*	*very coarse gravel*	*D84*	*34*	*very coarse gravel*

*Profiles and cross-sections re-established during Post-Restoration Year 1 (2017)

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